PHYTOTOXICOLOGY ASSESSMENT SURVEYS IN THE VICINITY OF ELDORADO RESOURCES LTD., PORT HOPE, 1986 AND 1987

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PHYTOTOXICOLOGY ASSESSMENT SURVEYS IN THE VICINITY OF ELDORADO RESOURCES LTD., PORT HOPE, 1986 AND 1987

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1. Executive Summary

The Phytotoxicology Section has conducted annual assessment surveys in te vicinity of Eldorado Resources Ltd. (ERL) in Port Hope since 1974. This report summarizes soil and vegetation surveys conducted in 1986 and 1987. These surveys confirmed that ERL is currently emitting U, F and to a lesser extent As, to atmosphere. Fluoride emissions are still high enough to injure vegetation, even though emission rates have declined from the 1970's and early 1980's. Surface soil concentrations of U, Cu, Ni, Pb, Zn, Fe, As, Co, Cr and Sb exceeded Phytotoxicology guidelines, with the most frequent and severe exceedances being detected for U, As and Sb. Soil concentrations of these elements are high enough at some sites to be phytotoxic to some plants. In addition, the radionuclides ^{226}Ra, ^{210}Pb and ^{238}U were detected in soil at activities which consistently exceeded reported background values. The soil contamination gradients for U, As, Sb, ^{238}U, ^{226}Ra and ^{210}Pb clearly indicate that the ERL complex is the main source. The areas of highest soil contamination are mostly within 500 m of ERL and correlate well with the zone of greatest long term deposition of atmospheric emissions as estimated by AES dispersion modellers.

Health and Welfare Canada has studied vegetable produce grown in Port Hope gardens contaminated with U and Ra and concluded that consumption of the crops represents neither a chemical nor a radiological hazard. However, the implications of potential health effects from exposure to soil contaminated with other elements and radionuclides at the concentrations encountered in some areas of Port Hope have not been fully examined. It is recommended, therefore, that the soil survey data be reviewed by the appropriate medical authorities to determine if soil remedial action is warranted.

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2. Introduction

The Phytotoxicology Section has conducted annual assessment surveys in Port Hope since 1974. The purpose of these surveys was to monitor the impact of emissions from Eldorado Resources Ltd. (now know as Cameco) on the local terrestrial ecosystem. Survey activities have included the collection and analysis of surface soil and tree foliage, the deployment of ion-receptor moss bags, and inspection of vegetation for the presence of characteristic air pollution injury symptoms. Also, complaint investigations regarding soil or vegetation contamination or injury have been conducted as requested by the public. This report summarizes the results of Phytotoxicology assessment surveys conducted in 1986 and 1987.

In 1986 and 1987, foliage was collected from maple trees at 12 established sample sites. In both years these samples were analyzed for total fluoride (F), uranium (U) and arsenic (As). In 1987 only, in addition to F, U and As, the tree foliage was analysed for total cadmium (Cd), copper (Cu), nickel (Ni), lead (Pb) and zinc (Zn). These additional metal analyses were performed to compare current (1987) data with metal concentrations detected in maple foliage in 1985.

In 1986, a soil survey was conducted at 36 sites throughout Port Hope to determine the severity and extent of U, As, Cd, chromium (Cr), Cu, Ni, Pb and Zn contamination of surface soil. Most of these soil sample sites were located on residential or municipal lawns. Grass was also collected from the same 36 sites and was analyzed for the same eight elements.

The 1986 soil survey was repeated in 1987 at 18 of the original 36 sample sites. Also, 23 new sites were sampled in 1987, primarily from areas of elevated levels identified in the 1986 survey. In addition to the eight elements for which data were obtained in 1986, the 1987 soil samples were analyzed for total iron (Fe), cobalt (Co), antimony (Sb) and selenium (Se). Selected 1987 soil samples also were analyzed for the radionuclides uranium 238 (^{238}U), thorium 228 (^{228}Th), radium 226 (^{226}Ra), radium 228 (^{228}Ra), potassium 40 (^{40}K) and lead 210 (^{210}Pb).

In both 1986 and 1987, the occurrence of air pollution injury symptoms on sensitive species of vegetation was carefully recorded.

3. Injury to Sensitive Species of Vegetation

Eldorado Resources Ltd. (ERL), now renamed Cameco, manufactures uranium hexafluoride and uranium dioxide which are used to produce fuel used to power nuclear generating stations. During the manufacturing process elemental F and U are released to atmosphere. Ambient levels of F in the vicinity of ERL are usually high enough to injure sensitive species of vegetation. Unlike F, ambient U does not cause direct vegetation injury, although U can accumulate in the soil to concentrations which are toxic to plants.

Fluoride produces characteristic injury symptoms on the foliage of sensitive species of vegetation. Manitoba and silver maple are used in the ERL assessment survey because they are moderately sensitive to ambient F, are well distributed in the Port Hope area, and have well defined background F concentrations.

Figure 1 illustrates the approximate location of the 12 maple foliage collection sites. In 1986, F-like injury symptoms were observed on Manitoba maple foliage at Sites 19 (300m W), 18 (300m NW) and 20 (300m E) and on silver maple foliage at Site 05 (750m ENE). Injury was only trace (<1%) to light (2-10%) at these sites. Unless otherwise stated, all distances and directions are approximate to a central location within the ERL complex. Generally, F injury to vegetation in Port Hope in 1986 was restricted to the area in the immediate vicinity of ERL and was relatively insignificant in extent and severity.

In 1987, F injury on maple foliage was more extensive and severe than in 1986. Moderate (11-35%) to severe (>35%) injury was observed at Site 20. Moderate injury also occurred at Sites 19, 18 and 05. Injury characteristic of F toxicity but only trace to light in severity was observed at sample Sites 22 (500m N) and 21 (1100m NE). Fluoride-like injury symptoms also were observed on a variety of indigenous and ornamental plants in 1987. These included tulip, hosta and canna lilies, wild grape, St. John's wort and gladiolus. These plants are extremely sensitive to ambient F. Injury was observed up to 1.5 km NE of ERL along Dorset St. East and Hope St. South and up to 500m along King St., Shuter St., Mill St., in the vicinity of the Town Hall, Dorset St. West and the area around the Alexander ravine. In 1986, F injury to these sensitive species of vegetation was quite rare and occurred only at a few locations immediately around ERL.

4. Results of Maple Foliage Analysis for Fluoride

In 1986 and 1987, triplicate samples of maple foliage were collected from the 12 sites illustrated in Figure 1. The samples were collected from the sides of the tree crowns facing ERL and were analyzed on a not-washed basis for total F, U and As. The 1987 samples also were analyzed for Cd, Cu, Ni, Pb and Zn.

The results of the F analyses of maple foliage are summarized in Table 1. The F concentrations of unwashed tree foliage in Port Hope in 1986 were the second lowest since annual sampling was initiated by the Phytotoxicology Section in 1974. The maximum concentration, 46 parts per million (ppm), was detected at Site 19, 300 m W of ERL. This is the only one of 12 sample sites where F levels exceeded the Phytotoxicology Upper Limit of Normal (ULN) urban guideline of 35 ppm. Foliar F levels in 1986 at the remaining 11 maple sample sites were within the range which can normally be encountered in an urban environment. There was,

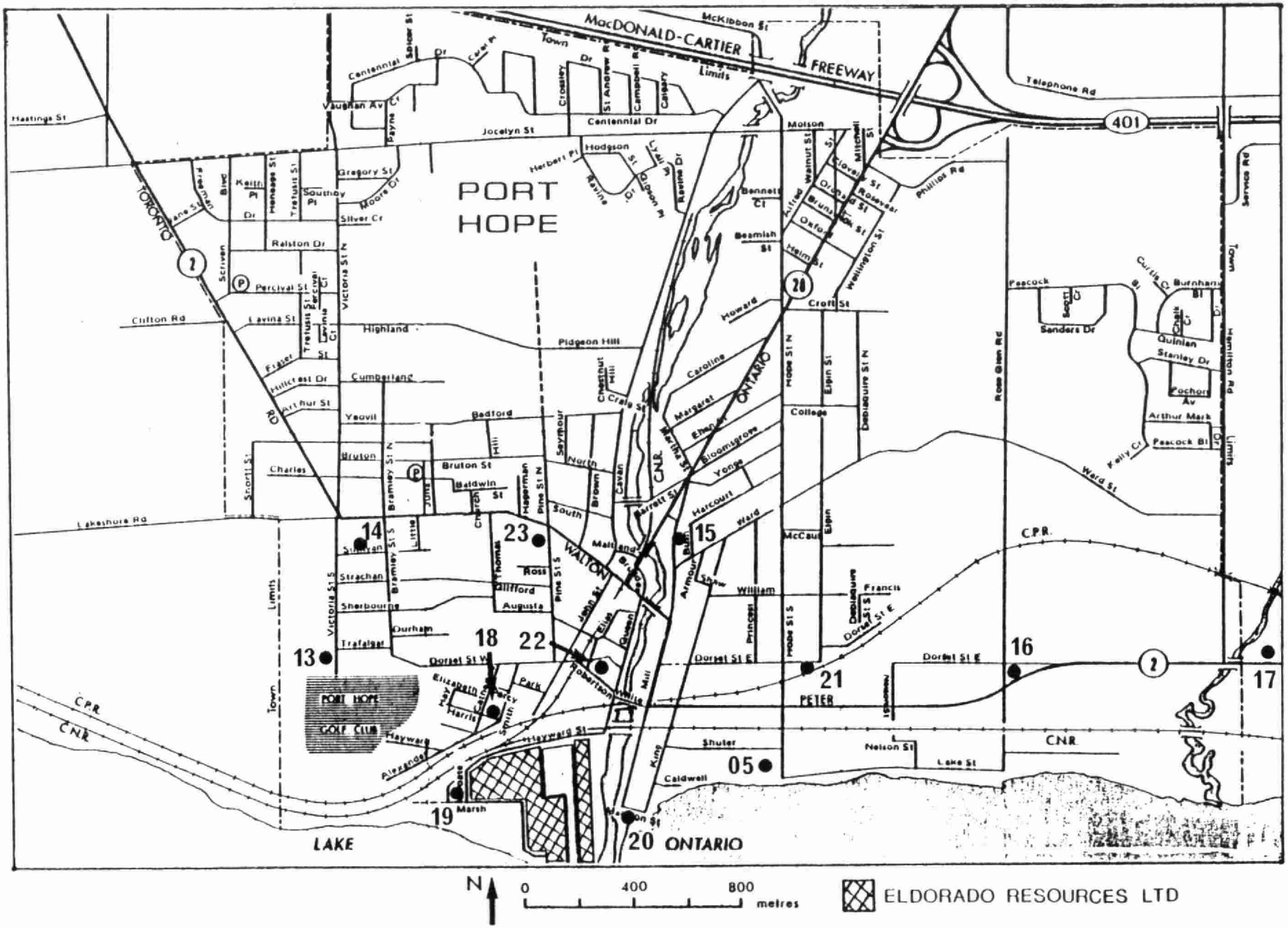


Figure 1: Maple Foliage Collection Sites.

Table 1: Fluoride Concentrations in Maple Foliage in the Vicinity of Eldorado Resources Ltd., Port Hope, 1974 to 1987

Site #	Distance & Direction from ERL	Fluoride Concentration*													
		1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
20	300 m E	**415**	**431**	**1330**	**700**	**142**	**64**	**1075**	**280**	**435**	**260**	20	**38**	20	**75**
05	750 m E	**175**	**126**	**183**	**122**	33	12	**250**	**45**	**44**	**360**	17	**59**	18	27
21	1100 m E	NC	NC	NC	21	11	9	**40**	18	23	15	8	**50**	16	12
16	1600 m E	**55**	23	33	19	7	4	**70**	21	32	16	9	13	10	26
17	2600 m E	**53**	**41**	**69**	28	14	9	30	16	**40**	22	12	18	11	18
Mean E Sites		**175**	**155**	**404**	**178**	**41**	20	**293**	**76**	**115**	**135**	13	**36**	15	32
22	500 m N	NC	NC	NC	**68**	15	15	18	32	**42**	16	10	22	8	23
15	750 m N	23	19	33	15	10	8	8	18	22	10	5	10	5	21
23	1000 m N	NC	NC	NC	NC	NC	NC	NC	11	7	2	3	4	3	7
Mean N Sites		23	19	33	**42**	13	12	13	20	24	9	6	12	5	17
18	300 m NW	NC	NC	NC	**37**	16	7	8	28	17	7	4	19	6	17
14	750 m NW	8	6	9	5	17	3	3	10	8	6	4	10	10	11
Mean NW Sites		8	6	9	21	12	5	6	19	13	7	4	15	8	14
19	300 m W	NC	NC	NC	**71**	9	31	**135**	**155**	**73**	**43**	10	**266**	**46**	**56**
13	750 m W	23	18	17	35	8	5	10	30	13	4	6	9	4	14
Mean W Sites		23	18	17	**53**	9	18	**73**	**93**	**43**	24	8	**138**	25	35
Mean All Sites		**94**	**83**	**209**	**102**	26	16	**150**	**54**	**63**	**63**	9	**43**	13	26
Phytotoxicology Upper Limit of Normal Guideline (exceedances in bold)									... 35 ...						

*Parts per million, not-washed, oven-dried, mean of replicate samples (3 per site)
NC - not collected

however, a recognizable F gradient relative to distance and direction from ERL. These relatively low foliar F concentrations corroborate the visual observations of limited injury symptoms on the maple trees sampled in 1986.

The F levels in tree foliage were higher at 11 of the 12 sites in 1987 compared with 1986. Two of the 12 sites exceeded the ULN guideline of 35 ppm. Maple foliage at Site 20 averaged 75 ppm F and foliar F levels averaged 56 ppm at Site 19. These two sites are the two closest to ERL. The mean foliar F concentration of all 12 sites in 1987 was twice the 1986 level. The higher F levels in maple foliage in 1987 reflect the greater extent and severity of F injury symptoms relative to the previous year.

The Phytotoxicology ULN guideline of 35 ppm does not imply toxicity, as very sensitive plant species can develop F injury symptoms at tissue concentrations below 35 ppm. Conversely, tolerant species of plants may not develop injury at several times this level. The guideline is based on an extensive review of control data from across the province. It was derived from the straightforward formula of the mean (of all the urban background data) plus three standard deviations. Statistically, 99% of all samples from an urban environment will be below 35 ppm; therefore, an investigator can state with confidence that levels of F above 35 ppm in vegetation are a result of exposure to an extraneous F pollution source. Phytotoxicology ULN guidelines have been developed for many other elements in addition to F.

Figure 2 illustrates the average annual foliar F concentration of the 12 Port Hope maple sample sites from 1974 to 1987. Fluoride levels in maple foliage over this time period have been highly variable, peaking at an average of 209 ppm in 1976. In this year the F level in maple foliage at Site 20, the location which historically has had the highest average F concentration, was 1330 ppm. By comparison, the survey mean and Site 20 maximum F concentrations were 13 ppm and 46 ppm in 1986 and 26 ppm and 75 ppm in 1987, respectively.

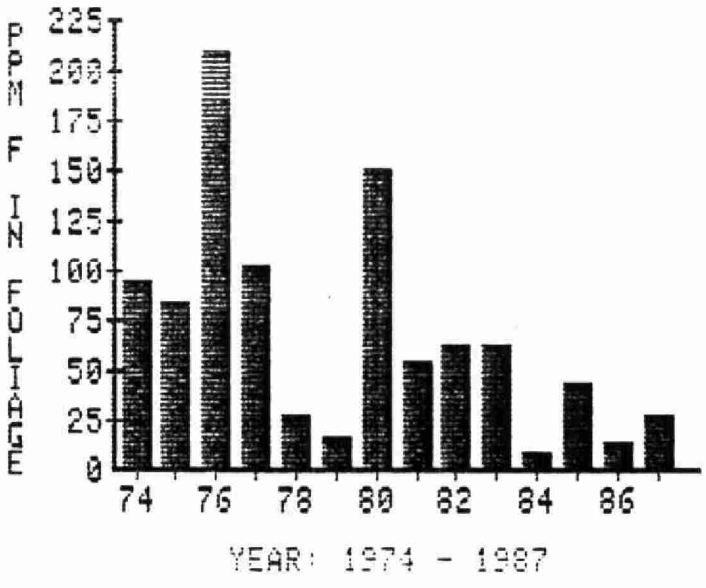


Figure 2: Survey Mean Fluoride Concentration in Maple Foliage : 1974-1987.

These data indicate that even though there has been a general trend towards lower F contamination in the vicinity of ERL, the company is still a source of plant-damaging F air pollution.

5. Results of Maple Foliage Analysis for Uranium

The Phytotoxicology Section has not established a ULN guideline for U because an insufficient number of control samples from Ontario have been analyzed for this element. The literature reports that plant tissue not exposed to a U pollution source consistently averages less than 1 ppm (Bowen, 1979). Similarly, the mean unpolluted soil U level normally does not exceed 2 ppm. The exceptions are U ore bodies and deposits of phosphatic rock in which soil U concentrations may average up to 90 ppm (Johnson, 1980). Reference data for background concentrations of U in soil and vegetation are summarized in Table 2. A tentative ULN for U, based on limited control sampling in Ontario and particularly in the Port Hope area, would be 3 ppm for tree foliage and 5 ppm for surface soil. These levels were established specifically for this survey area and probably are high due to the fact that a large portion of the background data were taken from this general area. Most likely, the actual ULN for U, when established, will be slightly lower.

Table 3 summarizes the annual maple foliage U data of the ERL surveys from 1980 to 1987. In 1986, the maximum U foliar concentration was 24 ppm, detected at Site 20 immediately east of ERL. Three of the 12 sample sites exceeded the tentative ULN of 3 ppm. In 1987 the foliar U levels were (generally) slightly lower than the previous year with the maximum concentration of 17 ppm being detected at Site 19, the closest site west of ERL. However, three of the 12 sample sites exceeded the tentative ULN again in 1987. In both years a definite foliar U contamination gradient relative to the ERL plant was apparent.

The annual mean U concentration in maple foliage from the 12 sample locations has varied considerably since 1980, as illustrated in Figure 3. The lowest annual 12-site mean U level was 3 ppm, which occurred in 1984. This represented a significant decrease compared to the mean of 30 ppm in

Table 2

Uranium in Soil and Vegetation: Reference Data*.

Sample Medium	Mean	Min.	Max.	Reference
(A) Soil				
- natural background	2.0	0.7	9.0	Bowen, 1979
- phosphatic rock (Idaho)	90		400	Johnson, 1980
- Elliot L. ore tailings		15.8	19.1	Moffet, 1977
- Port Hope veg. gardens (clean)	2.0			Tracey, 1983
- Port Hope veg. gardens (contam.)		7.5	420	Tracey, 1983
- Phytotoxicology survey, Port Hope		0.7	460	McLaughlin, 1986
- Darlington Prov. Park	1.0	1.0	1.0	McLaughlin, 1981
- significant yield reduction of sensitive crops		50		Nistha, 1978
(B) Plants				
- highly species specific		0.005	0.04	Bowen, 1979
- edible produce		0.01	0.06	Bowen, 1979
- Port Hope veg. produce (clean)	0.31			Tracey, 1983
- Port Hope veg. produce (contam.)		0.27	194	Tracey, 1983
- Port Hope maple foliage		2.0	173	McLaughlin, 1981
- Darlington Prov. Park maple foliage	0.6	0.4	0.8	McLaughlin, 1981

* Values are parts per million, dry weight.

Table 3: Uranium Concentration in Maple Foliage in the Vicinity of Eldorado Resources Ltd., Port Hope, 1980-1987

Site #	Distance & Direction from ERL	Uranium Concentration* 1980	1981	1982	1983	1984	1985	1986	1987
20	300 m E	**108**	**88**	**156**	**49**	10	13	24	11
05	750 m E	**19**	**25**	**32**	**84**	8	14	6	6
21	1100 m E	**10**	9	9	**24**	3	9	3	3
16	1600 m E	6	9	**10**	**16**	1	2	2	1
17	2600 m E	6	**16**	**10**	**38**	5	5	2	2
Mean E Sites		**30**	**29**	**43**	**42**	5	9	7	5
22	500 m N	**14**	**10**	9	**17**	3	7	2	1
15	750 m N	1	4	3	6	1	1	1	1
23	1000 m N	NC	7	2	**32**	1	1	1	1
Mean N Sites		8	7	5	**18**	2	3	1	1
18	300 m NW	5	**11**	4	**34**	1	8	3	2
14	750 m NW	1	**12**	1	4	ND	1	1	1
Mean NW Sites		3	**12**	3	**19**	1	5	2	2
19	300 m W	**127**	**59**	**41**	**42**	3	**34**	**12**	**17**
13	750 m W	7	9	5	9	1	4	1	2
Mean W Sites		**64**	**34**	**23**	**26**	2	**19**	7	**10**
Mean All Sites		**28**	**22**	**24**	**30**	3	**8**	5	4
Background (Darlington Prov. Park)		.... 0.6							
Tentative ULN (exceedances in bold)		.... 3							

* Parts per million, not-washed, oven-dried, mean of replicate samples (3 per site)
NC - not collected
ND - not detected

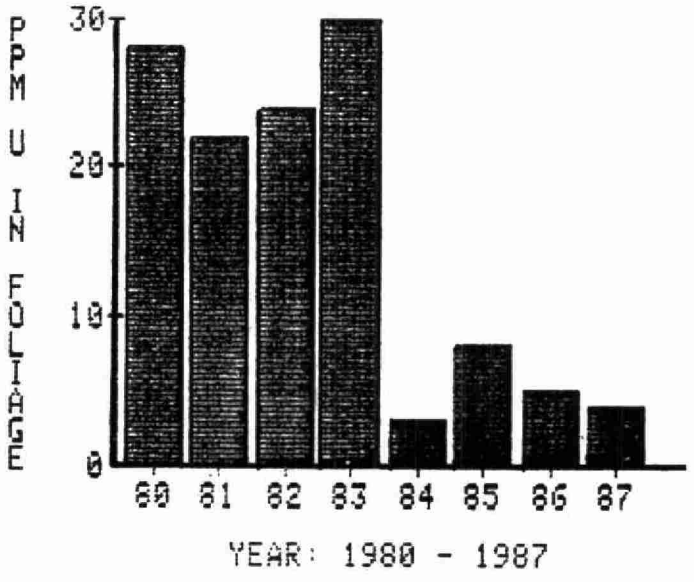


Figure 3: Survey Mean Uranium Concentration in Maple Foliage: 1980-1987.

the previous year. The U concentration of maple foliage from the sites closest to ERL frequently exceeded 100 ppm between 1980 and 1982. After 1983, maximum foliar U levels declined substantially, rarely exceeding 20 ppm.

These data indicate that even though there has been a substantial reduction in U contamination in the vinicity of ERL since 1983, foliar U concentrations at sites within 300 m of the company in 1986 and 1987 are still five to seven times higher than maximum expected background levels from areas not exposed to a U pollution source.

6. Fluoride and Uranium Foliar Relationship and Interlaboratory Comparison

The maple foliage collection sites with elevated F levels also have proportionally elevated U concentrations. Figure 4 illustrates the mean F and U foliar levels from the 12 sample sites from 1980 to 1987. These data have been log transformed because they are not normally distributed and the absolute value ranges between the elements are substantial. Figure 4 reveals that the foliar F and U levels vary in direct proportion to each other, thereby confirming their common source. Statistically, this relationship is highly significant (correlation coefficient = 0.892, $p < 0.01$) and can be described by the regression line equation: log ppm U = 0.144 (log ppm F) + 2.424. The F and U analyses are performed at separate laboratory stations; therefore, a F/U concentration ratio is a useful method of determining analytical accuracy. If the U concentration of maple foliage from a site is high but the F level is low, the investigator is alerted to the possibility that one of the analytical results may be in error and both analyses should be repeated. The mean F:U (not log transformed) ratio for all data collected since 1980 was 3.33:1. This ratio tends to increase as foliar F and U concentrations become very high, suggesting a non-linear relationship for untransformed data.

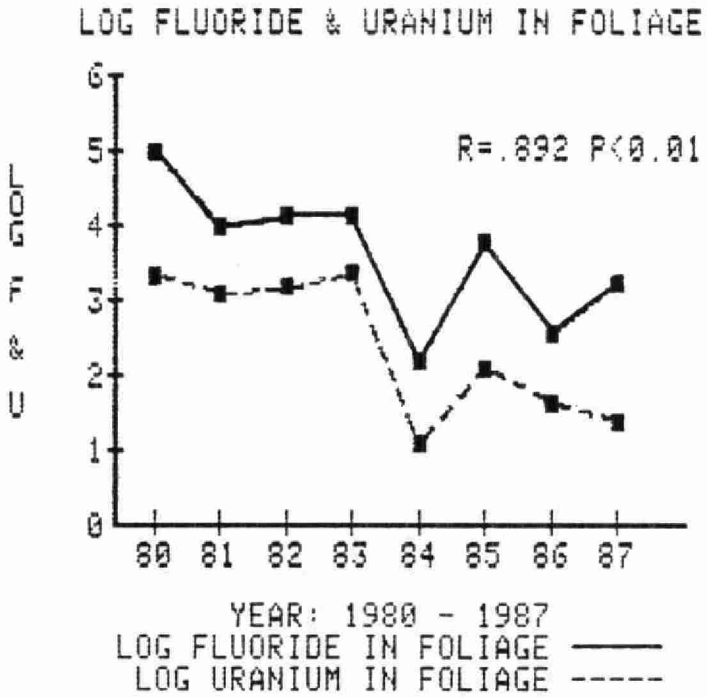


Figure 4: Relationship Between Fluoride and Uranium in Maple Foliage (data are log transformed).

An additional method is available for checking the accuracy of analytical results. All foliage samples have been collected in triplicate, with the replicates being processed and analyzed as separate samples. The results are averaged and it is the mean data which are cited in the report. Also, with the exception of 1985, the field samples were split between MOE and ERL sampling crews who returned the samples to their respective laboratories for analysis. To date, only F analytical results have been exchanged. Since 1981, the F analyses performed by the ERL laboratory have averaged approximately 15% higher than the MOE analyses. Although some variation is to be expected, the statistical relationship between MOE and ERL F analyses of the same samples is highly significant (correlation coefficient = 0.793, $p < 0.001$).

The Phytotoxicology Section has encouraged interlaboratory analytical comparisons of split field samples with other companies. It has been our experience that industrial laboratories invariably return a slightly higher analytical result than the MOE laboratory.

7. Heavy Metal Analyses Conducted in 1985 and 1987

In addition to F and U, the foliage collected from the 12 sample sites in the 1985 assessment survey was also analyzed for Cd, Cu, Ni, Pb and Zn. These additional analyses were performed at the request of the Port Hope Environmental Advisory Committee. These analyses were repeated in 1987 for comparison with the 1985 results. The 1985 and 1987 heavy metal maple foliage concentrations are summarized in Table 4. None of the metal concentrations exceeded the Phytotoxicology ULN guidelines. In addition, there were no concentration gradients relative to ERL. The Cd and Ni levels were consistently at or below the analytical detection limits. There was little variation between sites in the Cu, Pb and Zn concentrations of maple foliage.

These data confirm that emissions from ERL in both 1985 and 1987 were not a significant source of airborne Cd, Cu, Ni, Pb or Zn contamination.

Table 4: Heavy Metal Concentrations in Maple Foliage, Analyses Conducted in 1985 and 1987

Site No.	Distance and Direction from ERL	Concentration 1985/1987* Cd	Cu	Ni	Pb	Zn
20	300 m E	<0.1/0.1	6/6	<1/<1	5/4	15/18
05	750 m E	0.1/0.1	11/8	<1/<1	4/3	46/43
21	1100 m E	0.7/0.1	6/4	2/<1	12/5	17/16
16	1600 m E	0.1/0.1	11/8	<1/<1	11/6	31/36
17	2600 m E	0.2/0.1	6/5	<1/<1	13/6	24/26
Mean E Sites		0.2/0.1	8/6	<1/<1	9/5	27/28
22	500 m N	0.1/<0.1	7/4	1/<1	10/4	27/23
15	750 m N	<0.1/<0.1	7/4	<1/<1	10/4	20/18
23	1000 m N	<0.1/<0.1	9/12	<1/<1	6/2	12/12
Mean N Sites		<0.1/<0.1	8/7	<1/<1	9/3	20/18
18	300 m NW	0.1/<0.1	6/4	2/<1	4/2	18/17
14	750 m NW	<0.1/<0.1	6/5	<1/<1	6/3	13/19
Mean NW Sites		<0.1/<0.1	6/5	1/<1	5/3	16/18
19	300 m W	0.3/<0.1	6/4	1/<1	7/3	24/17
13	750 m W	0.1/0.2	6/4	<1/<1	3/2	9/11
Mean W Sites		0.2/0.1	6/4	<1/<1	5/3	17/14
Mean All Sites		0.2/<0.1	7/6	<1/<1	8/4	21/21
Phytotoxicology Upper Limit Of Normal**		3	20	7	60	250

* Parts per million, oven dry wt., mean of duplicate samples
** ULN described in report.

8. Results of Maple Foliage Analysis for Arsenic

Maple foliage collected in 1986 and 1987 was also analyzed for total As. The results of these analyses are summarized in Table 5. Arsenic concentrations marginally in excess of the Phytotoxicology ULN guideline of 2 ppm were detected in both years at Site 20, the sampling station closest and most directly downwind of ERL. Foliar As levels averaged 2.1 ppm at this site in 1986 and 1987. Although Site 20 was the only sample location to exceed the ULN, there was a clear gradient of foliar As levels relative to distance and direction from ERL.

These data indicate that As is currently being emitted by ERL at concentrations high enough to exceed vegetation guidelines. If the history of As emissions from this source has paralleled that of U and F, then As emissions were likely much higher in the late 1970's and early 1980's. The concept of historic As emissions is explored further in the section of this report summarizing the soil survey data.

9. 1986 Soil Assessment Survey

9.1 Results of Soil Uranium Analysis - 1986

The first Phytotoxicology soil survey in Port Hope was conducted in 1984. Triplicate surface soil samples were collected from each of 36 sites and analysed for total U. The results of this initial survey revealed that soil U contamination was present in an area approximately 7.9 km^2 in size centred on the area around the Ganaraska River mouth. It was also concluded that ERL was the source and that the U had originated predominantly from chronic, long term atmospheric emissions.

In 1986, the soil survey was repeated to confirm and characterize the contamination detected in the 1984 survey. The approximate locations of the 36 sample sites are illustrated in Figure 5. In addition to U, the replicate soil samples were analysed for total As, Cr, Cu, Ni, Pb and Zn. The soil samples were collected from three depths: 0 to 5 cm, 5 to 10 cm,

Table 5: Arsenic Concentrations in Maple Foliage in the Vicinity of Eldorado Resources Ltd., 1986 and 1987

Site No.	Distance and Direction from ERL	Concentration* 1986	1987
20	300 m E	**2.1**	**2.1**
05	750 m E	0.57	0.91
21	1100 m E	0.39	0.23
16	1600 m E	0.12	0.25
17	2600 m E	0.16	0.35
Mean E Sites		0.67	0.77
22	500 m N	0.24	0.40
15	750 m N	0.13	0.30
23	1000 m N	0.31	0.30
Mean N Sites		0.23	0.33
18	300 m NW	0.13	0.30
14	750 m NW	0.11	0.30
Mean NW Sites		0.12	0.30
19	300 m W	0.58	0.83
13	750 m W	0.14	0.30
Mean W Sites		0.36	0.57
Mean All Sites		0.42	0.55
Phytotoxicology Upper Limit of Normal**		2	

* Parts per million, oven dry, wt., mean of duplicate sampling
** ULN Described in report.

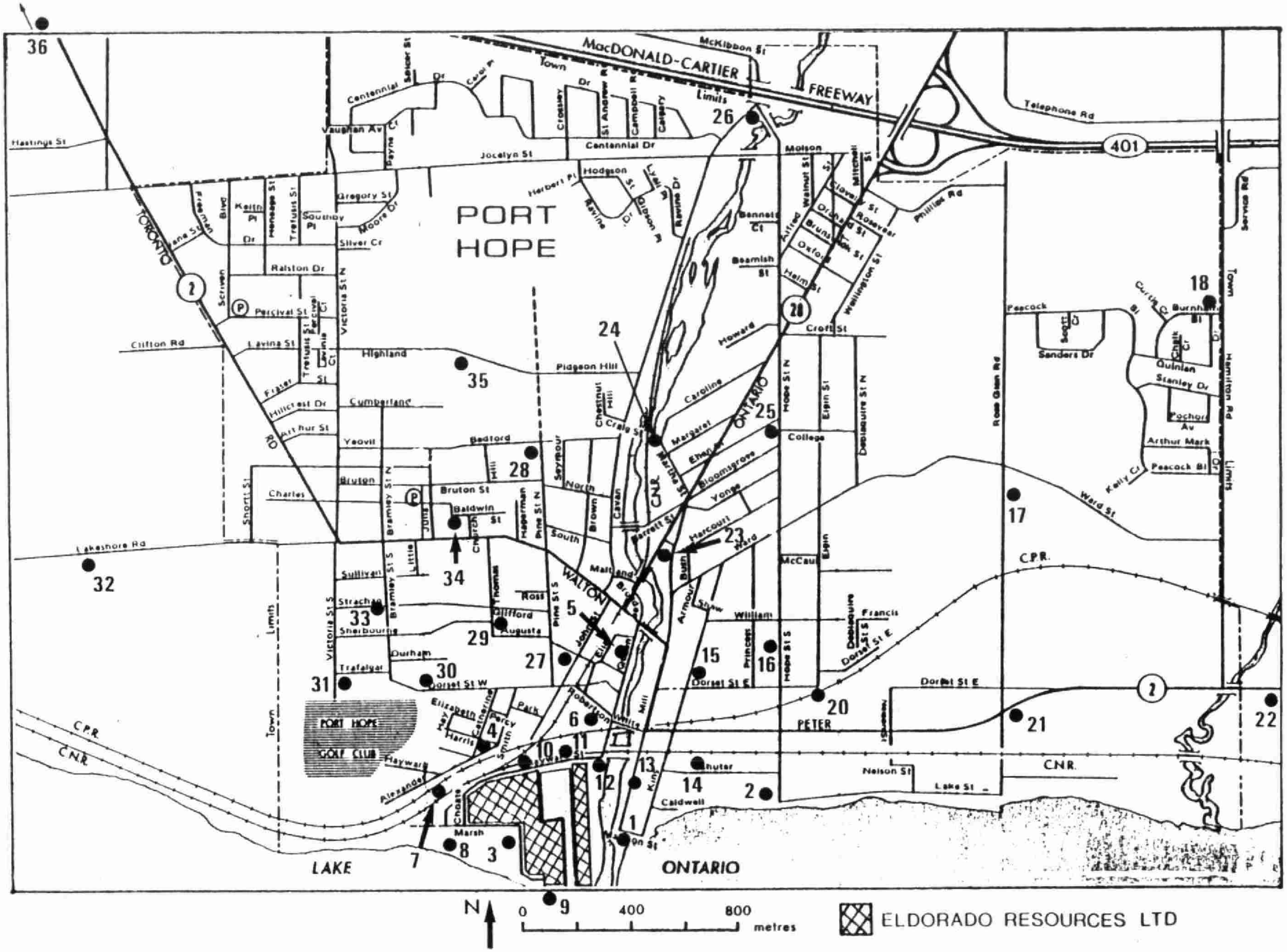


Figure 5: Soil and Grass Collection Sites (1986).

and 10 to 15 cm. Most of the sample locations were on municipal property; for example, lawns between the sidewalk and the street in residential areas, and places which are publicly accessible.

The 36 soil sites are in the immediate vicinity of the 36 moss bag stations which were established in Port Hope in 1982. These sites cover the town from both east and west town limits and from the Lake Ontario shoreline to Hwy. 401. However, the sample sites are concentrated within 1000 m of ERL because previous Phytotoxicology sampling has indicated that the greatest contamination gradient falls within this range.

The results of the 1986 soil analyses are summarized in Tables 6, 7 and 8, for the 0 to 5 cm, 5 to 10 cm and 10 to 15 cm sampling depths, respectively. These data were used in conjunction with the SYMAP computer program to produce contamination contour maps of the same scale as the site location map, Figure 5. SYMAP, an acronym for synigraphic computer mapping, was developed by Harvard University (Dougenik and Sheeham, 1976). The SYMAP program produces maps with spacially-arrayed data in pre-chosen value ranges. The program contours the data, defined as each datum pixel, by comparing each empty map pixel with the seven nearest data pixels weighted according to the inverse of the square of the distance to each, and includes a directional bias. Detailed objective contamination contour maps can be constructed with a minimum of speculative interpretation. It should be noted, however, that the zones depicted in the SYMAP are predicted based on extrapolations from the nearest sampling sites and may not precisely represent the actual soil contaminant levels at any given non-datum point. The main advantage of the SYMAP is that the concentration gradients are predicted by a mathematical model and therefore are not subject to human bias.

The highest soil U concentration detected in the 1986 survey was 139 ppm in the 10-15 cm depth sample from Site 1, 360 m ESE of ERL (Table 8). Similarly elevated soil U levels occurred at the two other sample depths from this site. By comparison, background U soil concentrations collected from Darlington Provincial Park consistently averaged less than 1 ppm.

Table 6: Results of Soil Chemical Analysis from the 1986 Soil Survey. Data for the 0 to 5 cm Sampling Depth.

Site No.	Distance & Direction from ERL	Metal Concentration (ppm)* U	As	Pb	Cu	Cd	Cr	Ni	Zn
1	360 m ESE	117	56.5	230	50	0.6	28	15	205
2	840 m ENE	23	7.9	340	200	0.4	34	78	330
3	140 m SSW	22	6.8	32	10	0.5	26	7	41
4	240 m NW	11	25.5	115	26	0.5	24	9	100
5	400 m NNE	7.1	12.5	92	24	0.4	36	12	150
6	600 m NNE	13	2.5	59	31	<0.2	38	9	75
7	280 m WSW	71	234	365	320	1.3	28	42	330
8	280 m SSW	79	24.5	53	27	0.6	31	13	79
9	400 m SSE	7.0	5.4	10	8	0.4	23	5	24
10	100 m NW	12	6.9	43	17	<0.2	22	10	51
11	200 m NNE	21	13.0	185	65	0.2	23	16	105
12	320 m NE	38	38.5	1300	92	1.5	18	30	565
13	360 m NE	44	54.4	165	56	0.6	50	17	170
14	720 m ENE	20	25.5	42	20	0.4	28	11	102
15	820 m NE	8.3	19.5	96	21	0.5	32	12	94
16	1080 m NE	6.0	6.1	68	18	0.2	83	12	69
17	2060 m NE	4.6	10.5	61	21	0.4	38	16	81
18	3000 m NE	0.8	2.4	14	14	0.4	36	13	52
19	4160 m NE	0.6	3.0	20	12	0.4	34	11	57
20	1100 m ENE	7.2	12.5	260	31	<0.2	46	23	120
21	1780 m ENE	9.0	7.4	83	41	0.6	34	12	73
22	2960 m ENE	4.1	5.3	63	19	0.8	37	15	120
23	960 m N	2.3	7.1	79	18	0.7	33	12	67
24	1420 m N	3.3	5.6	59	14	0.6	28	10	88
25	1700 m NNE	1.3	2.4	48	12	0.3	61	11	65
26	2700 m N	0.7	3.5	39	20	0.8	35	14	62
27	520 m N	10	18.5	265	34	0.9	27	10	130
28	1180 m NNW	1.3	1.8	16	8	<0.2	21	6	41
29	620 m NW	4.6	13.5	80	14	0.5	25	8	91
30	460 m NNW	9.1	25.0	330	21	0.4	23	9	240
31	840 m WNW	6.8	3.9	26	9	<0.2	22	7	39
32	1560 m WNW	1.0	3.8	20	17	<0.2	69	7	59
33	980 m NW	5.5	28.0	60	16	<0.2	21	8	84
34	1060 m NW	2.7	8.8	150	15	0.4	21	8	180
35	1580 m NNW	1.7	5.5	20	7	0.2	22	8	36
36	2800 m NW	1.2	7.8	175	20	0.5	21	9	105
Phytotoxicology Upper Limit of Normal** (Exceedances in bold)		***5	20	500	100	4	50	60	500
Phytotoxicology Recommended Residential Clean-up Guideline+ (Exceedances underlined)		NE	25	500	200	4	1000	200	800

* Parts per million, air dry wt., mean of triplicate samples, 0-5 cm depth
** ULN described in report (based on 0-5 cm depth)
*** Tentative ULN, for information only
NE - Not established
+ CUG described in report

Table 7: Results of Soil Chemical Analysis from the 1986 Soil Survey. Data for the 5 to 10 cm Sampling Depth.

Site No.	Distance & Direction from ERL	Metal Concentration (ppm)* U	As	Pb	Cu	Cd	Cr	Ni	Zn
1	360 m ESE	73	46.5	485	52	0.5	25	13	195
2	840 m ENE	34	7.6	245	175	0.4	37	43	340
3	140 m SSW	35	12.1	41	12	0.5	27	8	56
4	240 m NW	7.1	24.0	103	18	0.5	24	9	96
5	400 m NNE	6.0	16.0	88	21	0.4	35	11	140
6	600 m NNE	8.7	2.4	56	21	<0.2	27	8	62
7	280 m WSW	5.3	160	285	215	0.9	26	33	215
8	280 m SSW	59	19.0	42	39	0.4	30	12	71
9	400 m SSE	3.1	5.0	10	7	0.2	21	5	24
10	100 m NW	9.4	4.8	32	15	<0.2	23	10	45
11	200 m NNE	20	14.5	185	59	0.3	24	15	105
12	320 m NE	31	51.5	9700	87	5.3	52	30	4330
13	360 m NE	37	77.5	210	74	0.7	49	20	200
14	720 m ENE	17	19.0	32	18	0.5	29	11	97
15	820 m NE	5.5	20.5	175	20	0.5	30	12	93
16	1080 m NE	5.4	5.4	60	19	0.2	89	13	73
17	2060 m NE	3.3	7.8	54	18	0.3	37	16	79
18	3000 m NE	0.6	2.3	13	15	0.4	36	13	49
19	4160 m NE	0.7	2.8	28	12	0.7	33	12	65
20	1100 m ENE	3.0	9.5	165	27	<0.2	44	23	99
21	1780 m ENE	5.6	7.1	120	21	0.7	35	12	94
22	2960 m ENE	3.2	5.2	53	19	0.8	39	16	125
23	960 m N	2.5	7.3	75	18	0.7	33	12	63
24	1420 m N	2.8	5.7	51	13	0.7	29	10	89
25	1700 m NNE	1.4	2.6	54	13	<0.2	54	11	66
26	2700 m N	0.8	3.4	47	19	0.8	34	13	60
27	520 m N	8.5	20.0	245	37	0.8	26	11	130
28	1180 m NNW	1.7	1.8	14	7	<0.2	20	6	34
29	620 m NW	4.6	19.0	91	15	0.5	23	8	92
30	460 m NNW	8.5	12.5	240	17	0.2	21	9	165
31	840 m WNW	5.8	4.0	26	10	<0.2	22	7	38
32	1560 m WNW	0.6	2.9	16	12	<0.2	46	7	48
33	980 m NW	5.1	21.5	54	15	0.2	21	7	72
34	1060 m NW	2.9	8.5	145	14	0.5	22	8	195
35	1580 m NNW	1.3	4.1	15	6	<0.2	21	7	30
36	2800 m NW	1.2	4.2	117	15	0.35	22	8	80
Phytotoxicology Upper Limit of Normal** (Exceedances in bold)		***5	20	500	100	4	50	60	500
Phytotoxicology Recommended Residential Clean-up Guideline+ (Exceedances underlined)		NE	25	500	200	4	1000	200	800

* Parts per million, air dry wt., mean of triplicate samples, 5-10 cm depth
** ULN described in report (based on 0-5 cm depth)
*** Tentative ULN, for information only
+ CUG described in report

Table 8: Results of Soil Chemical Analysis from the 1986 Soil Survey. Data for the 10 to 15 cm Sampling Depth.

Site No.	Distance & Direction from ERL	Metal Concentration (ppm)* U	As	Pb	Cu	Cd	Cr	Ni	Zn
1	360 m ESE	**139**	**67.5**	410	**104**	0.6	29	18	285
2	840 m ENE	**5.8**	7.4	325	**165**	0.3	39	54	415
3	140 m SSW	**13**	7.6	27	11	0.4	28	8	40
4	240 m NW	**8.2**	**33.0**	101	17	0.5	23	9	105
5	400 m NNE	**7.3**	**21.5**	85	23	0.6	41	12	115
6	600 m NNE	5.9	2.6	38	23	<0.2	30	8	62
7	280 m WSW	**41**	**169**	395	**230**	0.8	25	35	180
8	280 m SSW	**31**	18.0	34	19	0.5	30	12	56
9	400 m SSE	1.7	3.7	10	8	<0.2	23	6	28
10	100 m NW	**8.2**	3.7	25	15	<0.2	24	10	43
11	200 m NNE	**13**	14.0	150	45	<0.2	22	14	94
12	320 m NE	**21**	**84.5**	**1310**	**101**	1.3	29	26	455
13	360 m NE	**36**	**81.5**	220	74	0.7	**53**	22	240
14	720 m ENE	**16**	**24.5**	39	20	0.4	30	12	111
15	820 m NE	**8.0**	**24.0**	110	21	0.6	31	12	91
16	1080 m NE	3.2	7.1	58	18	0.2	**104**	14	67
17	2060 m NE	2.2	7.1	48	17	0.4	38	16	70
18	3000 m NE	0.8	2.1	12	22	0.3	36	13	47
19	4160 m NE	0.5	3.1	17	10	0.7	32	12	51
20	1100 m ENE	**8.9**	12.0	190	29	<0.2	42	22	115
21	1780 m ENE	3.9	9.0	165	23	0.9	35	13	109
22	2960 m ENE	2.4	5.0	52	20	0.8	39	16	125
23	960 m N	1.7	8.9	86	17	0.7	33	12	61
24	1420 m N	1.9	6.0	44	11	0.6	27	10	86
25	1700 m NNE	0.6	2.7	35	11	<0.2	**53**	10	50
26	2700 m N	0.7	3.9	38	20	0.8	35	14	65
27	520 m N	**7.8**	**22.5**	275	37	0.8	27	12	125
28	1180 m NNW	0.94	1.9	13	6	<0.2	19	6	31
29	620 m NW	3.2	18.0	91	15	0.7	23	7	82
30	460 m NNW	**6.6**	19.0	260	19	0.6	25	10	165
31	840 m WNW	4.7	3.9	27	10	<0.2	21	7	38
32	1560 m WNW	1.0	5.3	20	17	<0.2	**56**	8	56
33	980 m NW	4.4	**29.0**	44	15	<0.2	21	9	72
34	1060 m NW	2.5	8.5	170	14	0.4	22	9	155
35	1580 m NNW	0.4	3.4	12	5	<0.2	18	7	28
36	2800 m NW	0.9	6.7	123	12	0.4	21	9	74
Phytotoxicology Upper Limit of Normal** (Exceedances in bold)		***5	20	500	100	4	50	60	500
Phytotoxicology Recommended Residential Clean-up Guideline+ (Exceedances underlined)		NE	25	500	200	4	1000	200	800

* Parts per million, air dry wt., mean of triplicate samples, 10-15 cm depth
** ULN described in report (based on 0-5 cm depth)
*** Tentative ULN, for information only
\+ CUG described in report
NE Not established

The literature suggests that the average background level of U in surface soil is approximately 2 ppm (Table 2). On the basis of the data in Table 2, a tentative Phytotoxicology ULN for U in urban soil is suggested at 5 ppm. In total, 22 of the 36 soil sample sites from the 0-5 cm depth, 20 from 5-10 cm and 17 from 10-15 cm exceeded the tentative ULN for U (see summary Table 9).

Figures 6 (0-5 cm), 7 (5-10 cm) and 8 (10-15 cm) are SYMAPs illustrating the predicted contamination gradient for U in soil in Port Hope. These data illustrate that the soil U concentrations are directly related to distance and direction from ERL. Soil U levels decrease sharply with increasing distance from the source, although concentrations consistently above background are widespread. Uranium levels greater than 25 ppm were predicted up to 1200 m E and W of ERL. Soil containing greater than 5 ppm U was predicted up to 1.0 km N, 1.8 km W, and greater than 2.4 km E of the source. From the soil survey data, the SYMAPs predicted an area of approximately 7 km^2 that had surface soil U levels which exceeded the published literature average background of 2 ppm. This area extends beyond the east and west town lines, between Highland and Jocelyn Sts. in the north, and runs south to the Lake Ontario shoreline. These contamination zones, (numbers 2 to 5 on the U SYMAPs) encompass more than one half of the Port Hope town limits. A similarily significant portion of the survey area (about 4 km^2) was found to have soil U levels in excess of the tentative ULN guideline of 5 ppm.

9.2 Results of Soil Arsenic Analysis - 1986

The maple foliage survey indicated that As is currently being emitted by ERL. The maximum soil As concentration was 234 ppm, detected in the 0 to 5 cm depth at Site 7, 280 m WSW of ERL (Table 6). This is more than 11 times the Phytotoxicology ULN guideline for As of 20 ppm. In fact, the ULN was exceeded at nine sites in the 0 to 5 cm depth, seven sites in the 5 to 10 cm depth and at 10 sites in soil collected from 10 to 15 cm (Table 9). Although the As data had a greater degree of varability between

Table 9: The Mean Soil Concentration by Sampling Depth and the Number of Sample Sites which Exceeded Phytotoxicology Guidelines: 1986 Survey

Sample Depth (cm)	U	As	Cd	Cr	Cu	Ni	Pb	Zn
			Mean Concentration (ppm)*					
0-5	16.0	19.9	0.5	33	37	14	138	119
5-10	11.7	17.7	0.6	32	33	13	371	217
10-15	11.5	20.7	0.4	33	34	14	145	111
			Number of Sites Exceeding ULN**					
0-5	22	9	0	3	2	1	1	1
5-10	20	7	1	3	2	0	1	1
10-15	17	10	0	4	4	0	1	0
			Number of Sites Exceeding CUG***					
0-5	NE	7	0	0	1	0	1	0
5-10	NE	4	1	0	1	0	1	1
10-15	NE	6	0	0	1	0	1	0

* Mean 36 Samples Sites
** ULN, Upper Limit of Normal (urban soil), based on data for 0-5 cm sampling depth.
*** CUG, Clean-up Guidelines (residential/parkland land use)
NE Guideline not established

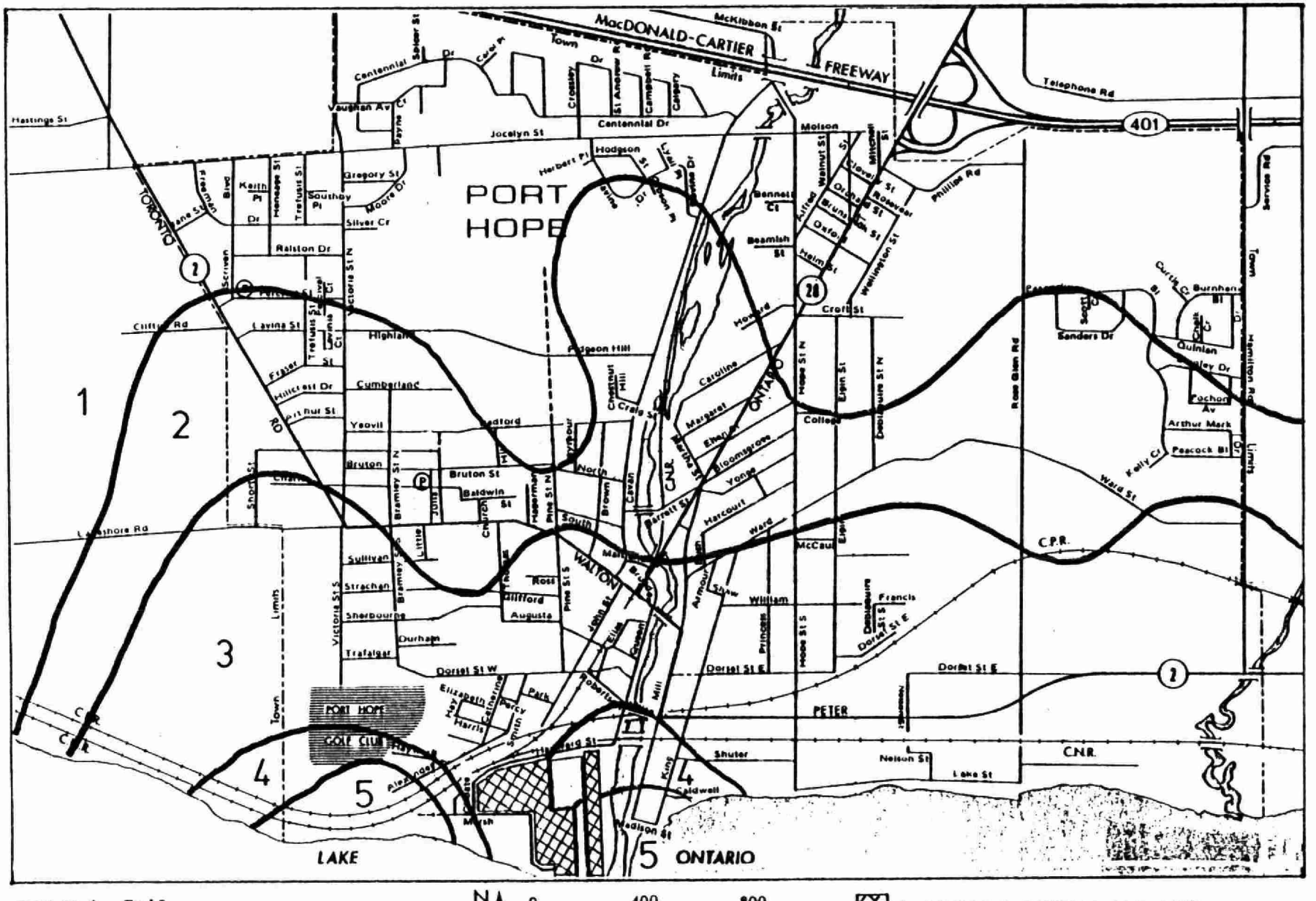


Figure 6: Contours of Uranium in Soil, as Estimated by SYMAP (1986, 0-5 cm depth).

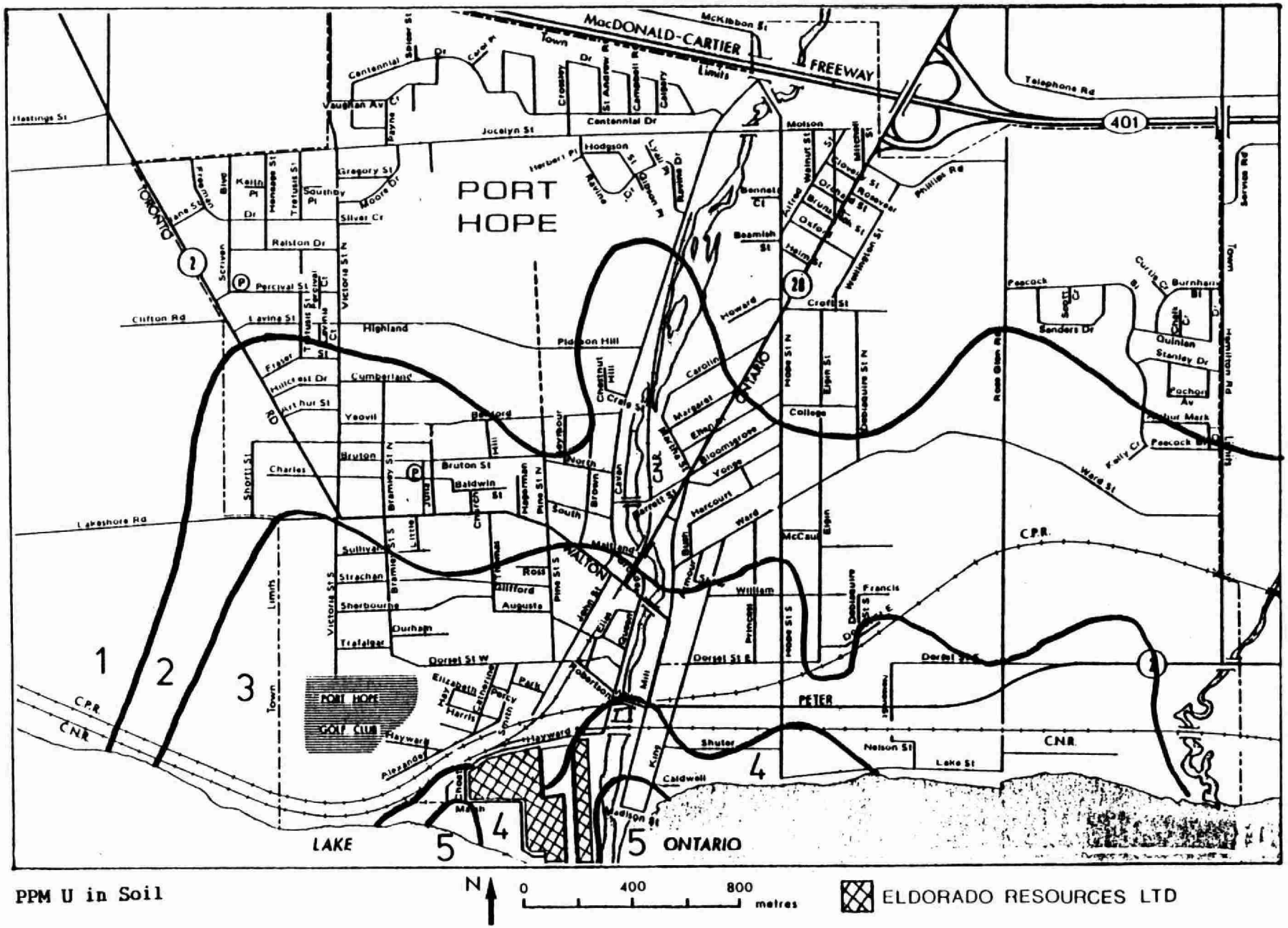


Figure 7: Contours of Uranium in Soil, as Estimated by SYMAP (1986, 5-10 cm depth).

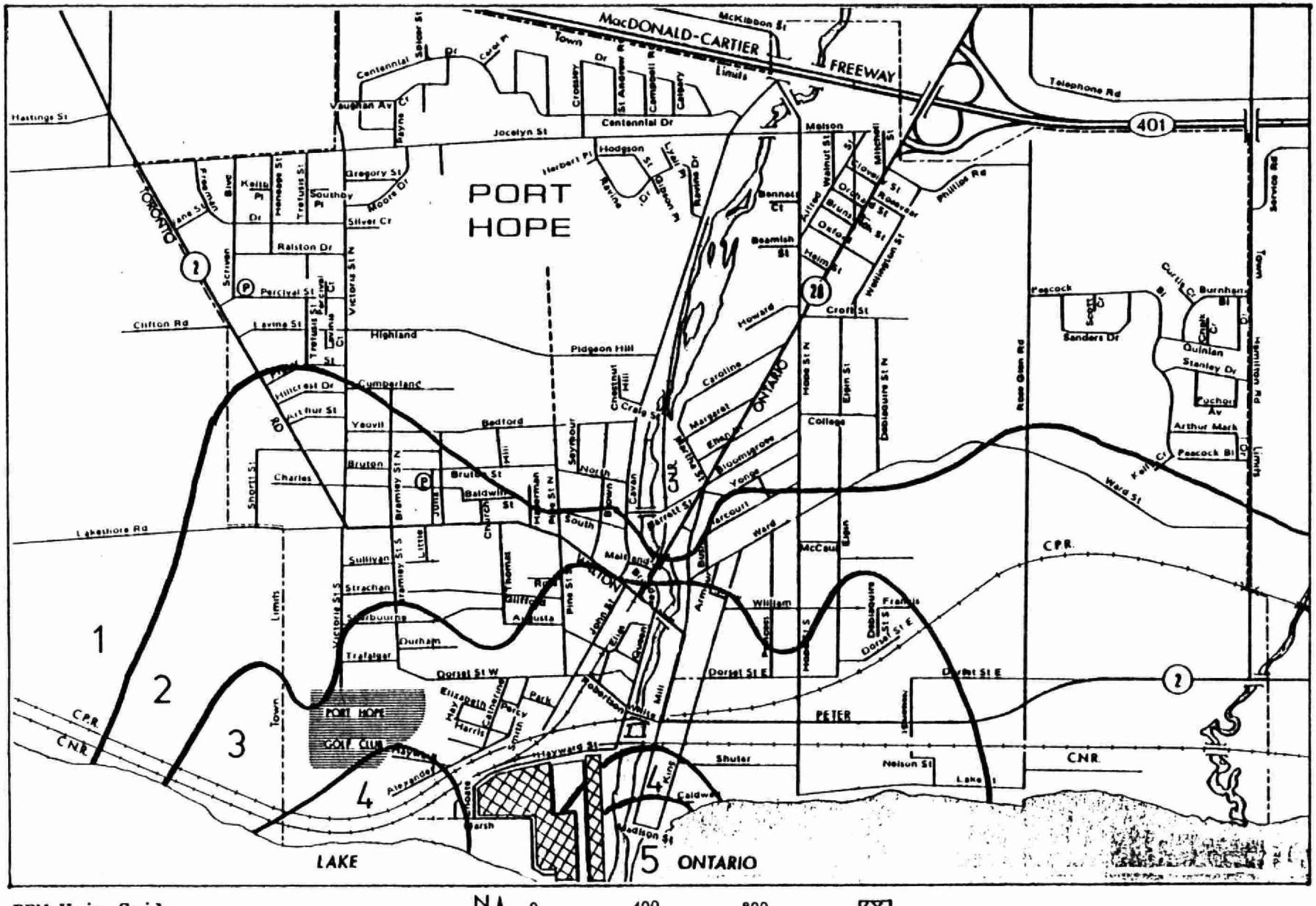


Figure 8: Contours of Uranium in Soil, as Estimated by SYMAP (1986, 10-15 cm depth).

sites, and even between replicates at the same site, than the U data, the contamination gradients of the two elements are similar. The As SYMAPs are Figures 9 (0-5 cm), 10 (5-10 cm) and 11 (10-15 cm). These SYMAPs illustrate that the area of highest As soil contamination lies between 600 m E and 800 m W of ERL, and that the levels decrease rapidly with increasing distance.

Soil As concentrations exceeding the 20 ppm ULN were predicted up to 1.2 km W, 1.6 km NW, 1.0 km NE and 800 m E of ERL. This covers an area of approximately 1.7 km^2, mostly south of Dorset Street and between the west town limits and west of Hope Street S. These data suggest that ERL was at some time in the past a considerable source of As emissions.

The Phytotoxicology Section has recommended a soil clean-up (site decommissioning) guideline for residential/parkland land use of 25 ppm As (50 ppm for industrial/commercial use), based upon potential phytotoxicity. The residential guideline was exceeded at 7 sites.

9.3 Results of Soil Pb Analysis - 1986

The Pb data were even more variable than the As results. In addition to considerable variation between sample sites, there was some very substantial variation between samples replicated at the same site. The site with the greatest variability between depths also had the greatest replicate variation and was the site with the survey maximum soil Pb concentration. The 5 to 10 cm depth at Site 12, 320 m NE of ERL, had a mean soil Pb level of 9700 ppm (Table 7). However, the sample replication was very poor, ranging from 400 ppm to 19000 ppm. These results would have been discarded or the analysis repeated except that other sampling depths from this site also had high Pb levels. Zinc and Cd levels in the 5 to 10 cm samples were also high. The Pb concentration in the 0 to 5 cm soil sample averaged 1300 ppm, while 1310 ppm was the mean Pb level in the 10 to 15 cm depth. The sample variation within replication at both these depths was acceptable.

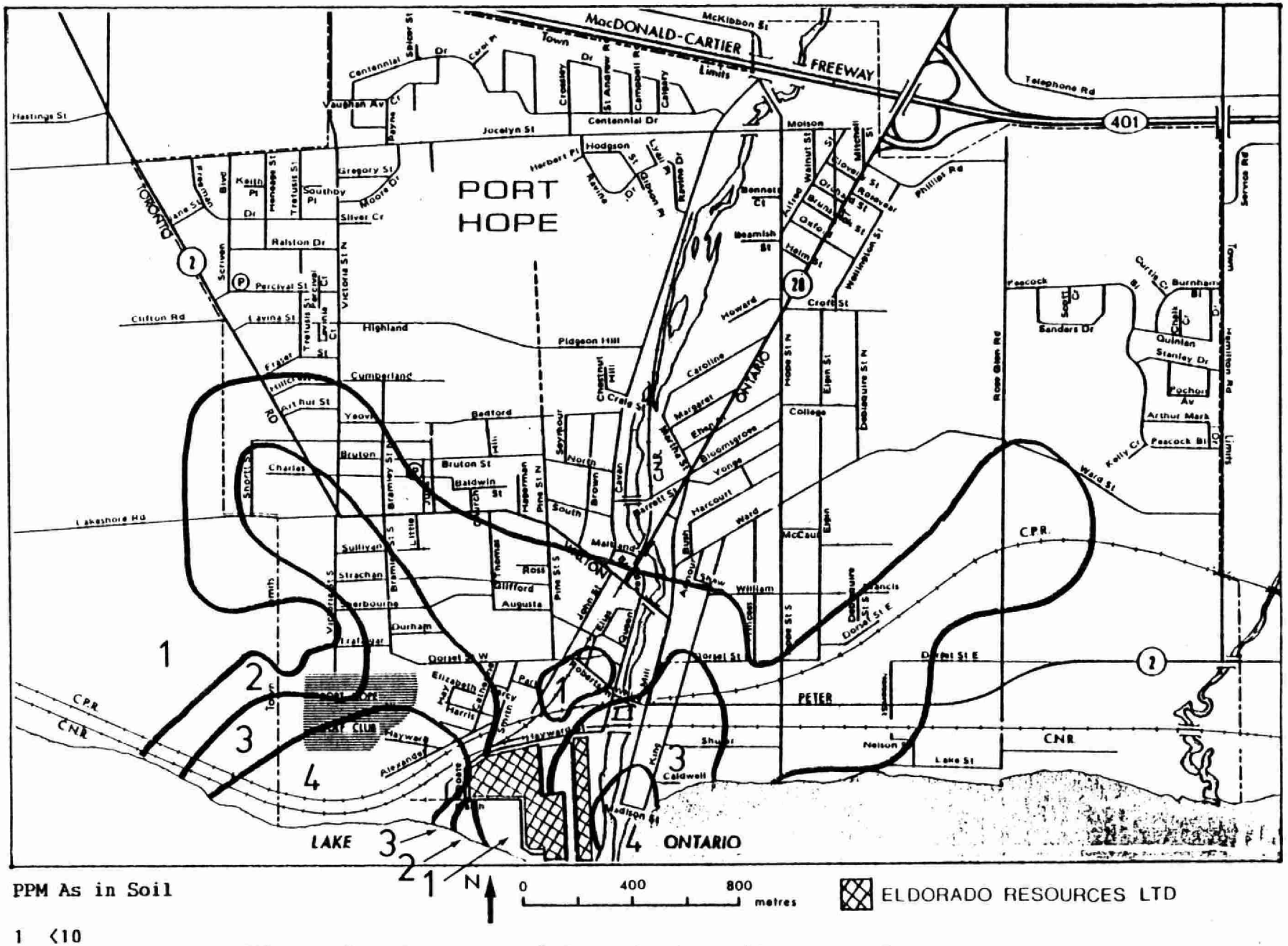


Figure 9: Contours of Arsenic in Soil, as Estimated by SYMAP (1986, 0-5 cm depth).

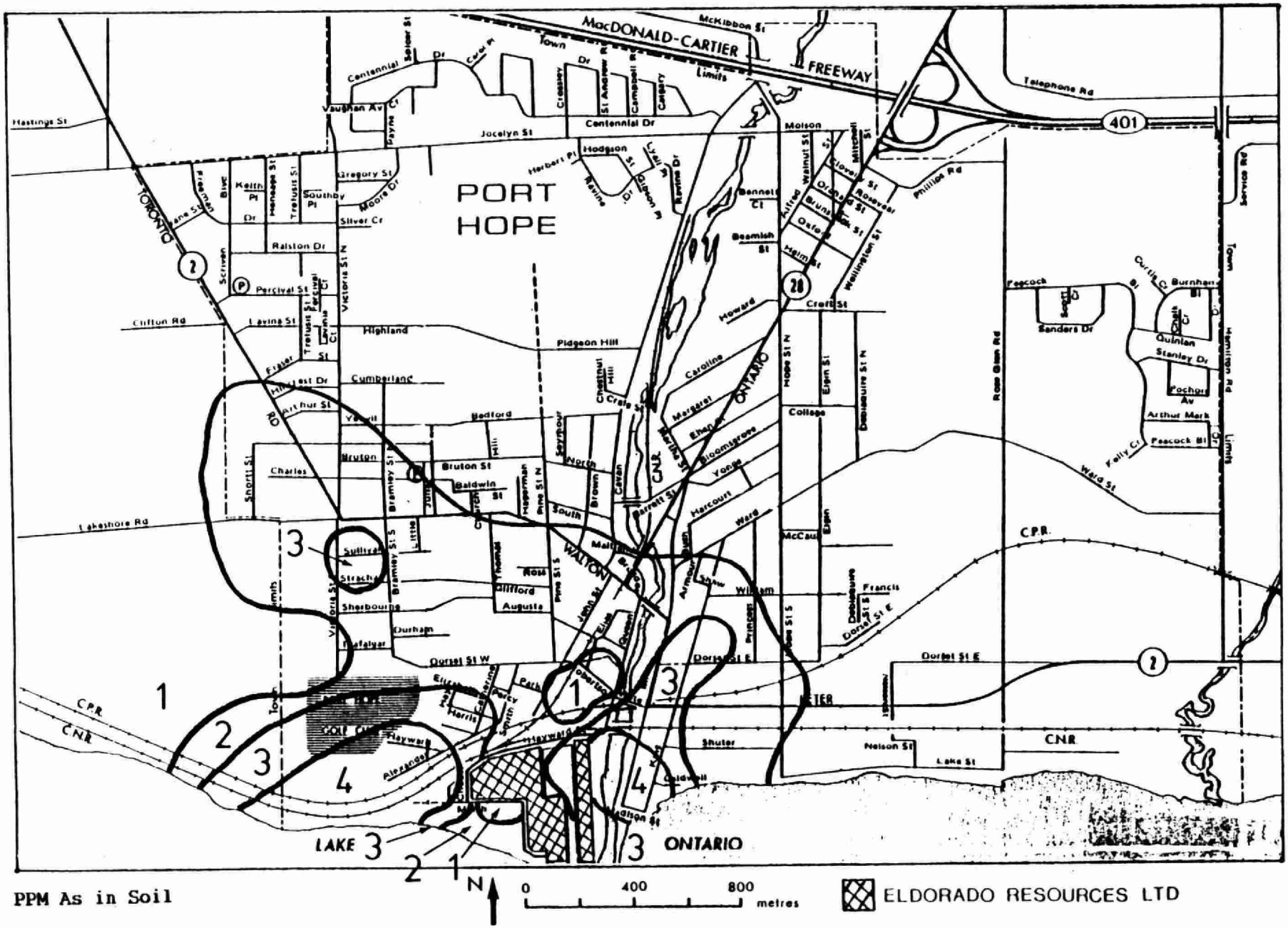
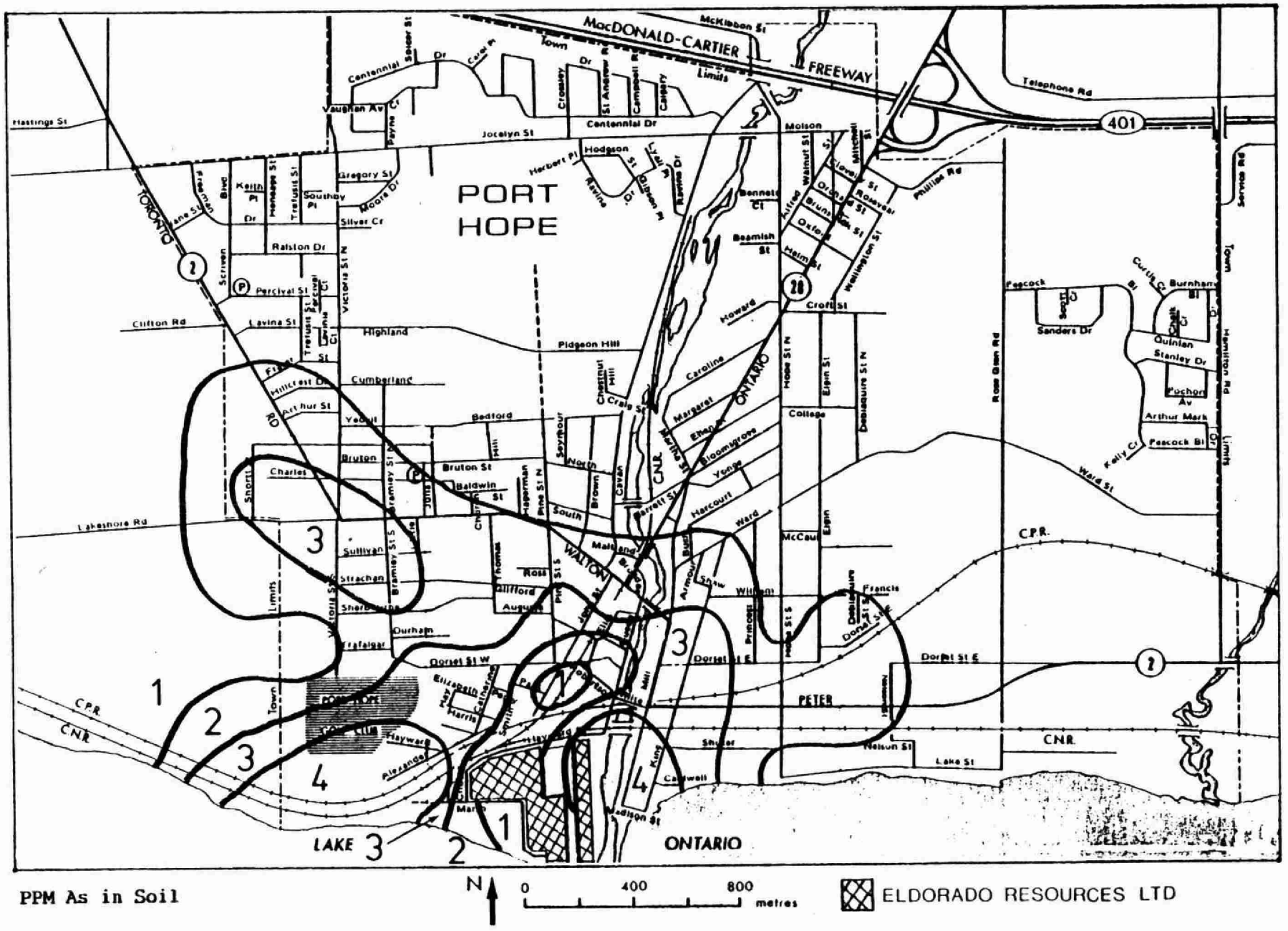


Figure 10: Contours of Arsenic in Soil, as Estimated by SYMAP (1986, 5-10 cm depth).



PPM As in Soil

1 <10
2 10-20
3 21-50
4 >50

Figure 11: Contours of Arsenic in Soil, as Estimated by SYMAP (1986, 10-15 cm depth).

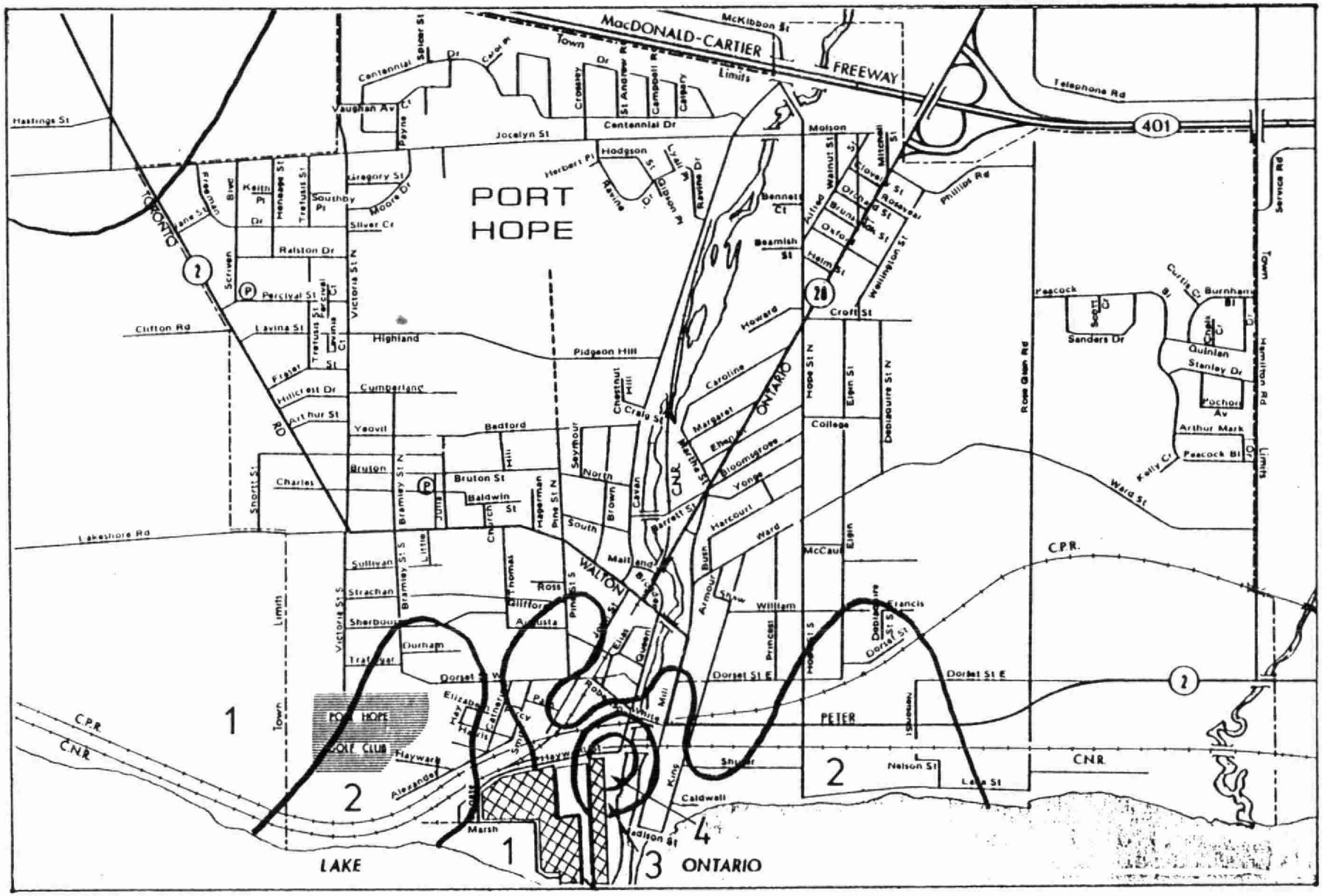
Replicate Pb analyses were quite variable at several other sample sites, although not as great as encountered at Site 12. Although the Pb SYMAPs (Figures 12, 13 and 14; 0-5 cm, 5-10 cm, and 10-15 cm respectively) clearly illustrate a contamination gradient relative to ERL, the site to site variability produces a somewhat complicated pattern of islands of high and low soil Pb levels. Generally, soil Pb concentrations above 150 ppm were restricted to an area within 1.0 km E and W and about 800 m N of ERL. However, within this zone were pockets of soil containing much higher and much lower Pb levels. The level of 150 ppm Pb is the Phytotoxicology ULN for a rural soil.

The Phytotoxicology ULN guideline for soil Pb in an urban environment is 500 ppm. This is also the recommended clean-up guideline for residential land use. However, soil data from other relatively small towns similar in size to Port Hope (population about 10,500) suggests that 500 ppm is high and that a normal range of soil Pb in these communities would be up to 150 ppm, the rural ULN value. This level better illustrates what is elevated above background for Port Hope. The area of soil Pb concentrations in excess of 150 ppm correlates well with the areas of elevated As and U levels, therefore suggesting a common source. The relationship between elements detected in soil is explored further in the section of the report which discusses the statistical analysis of the 1987 soil data (Section 15). However, since elevated Pb levels were not detected in foliage, ERL is not a significant current Pb source.

9.4 Results of Soil Cu Analysis - 1986

Four of the 36 sample sites exceeded the Phytotoxicology ULN soil Cu guideline of 100 ppm at one or more depths. The maximum Cu concentration was 320 ppm, detected in soil 0 to 5 cm deep at Site 7, 280 m WSW of ERL. The two other sampling depths at this site also marginally exceeded the 200 ppm recommended clean-up guideline.

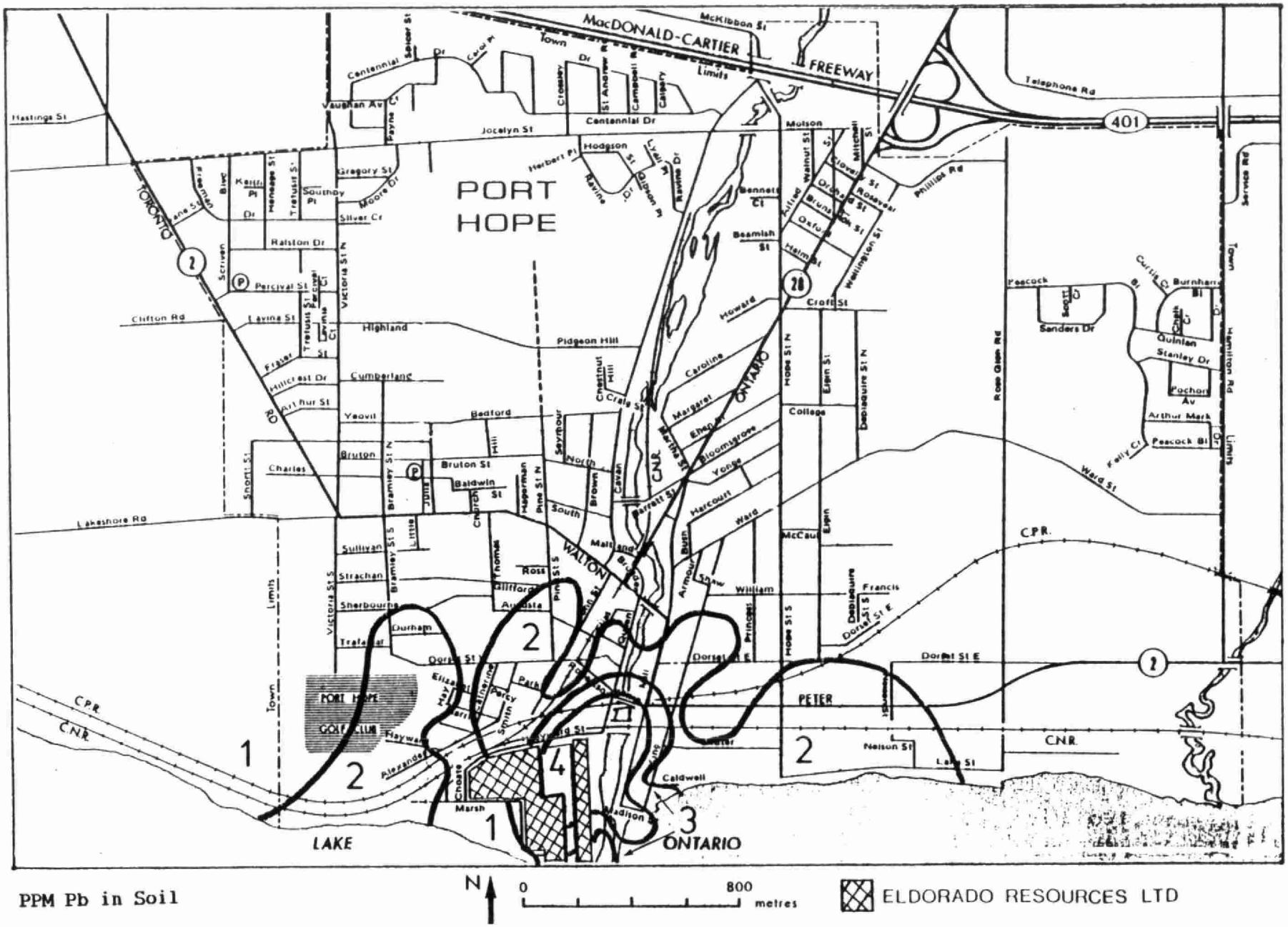
Soil Cu concentrations over 100 ppm were detected in pockets up to 1.0 km E and W and immediately north of ERL.



PPM Pb in Soil

1 <150
2 150-500
3 501-750
4 >750

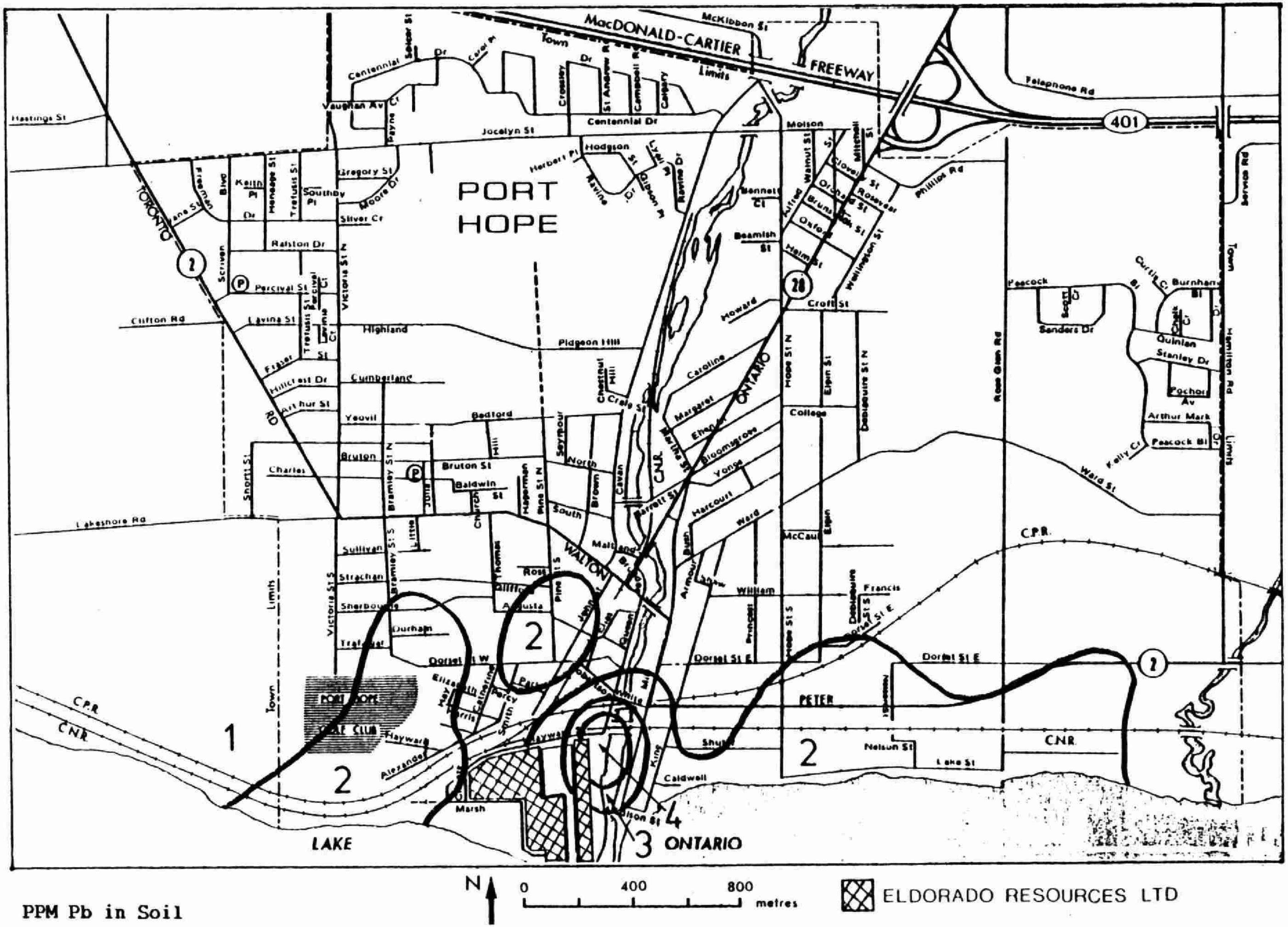
Figure 12: Contours of Lead in Soil, as Estimated by SYMAP (1986, 0-5 cm depth).



PPM Pb in Soil

1 <150
2 150-500
3 501-750
4 >750

Figure 13: Contours of Lead in Soil, as Estimated by SYMAP (1986, 5-10 cm depth).



PPM Pb in Soil

1 <150
2 150-500
3 501-750
4 >750

Figure 14: Contours of Lead in Soil, as Estimated by SYMAP (1986, 10-15 cm depth).

The Cu SYMAPs (Figures 15, 16 and 17; 0-5 cm, 5-10 cm and 10-15 cm, respectively) suggest a double contamination gradient, one located west of ERL centered on Alexander Street and the second to the east between the river mouth and the bottom of Hope Street S.

Although the pattern of soil contamination is suggestive of long term historic deposition, the foliar data do not indicate that ERL is a current Cu source.

9.5 Results of Soil Cd, Cr, Ni and Zn Analysis - 1986

The four remaining elements, Cd, Cr, Ni and Zn, each exceeded their respective ULN guidelines at at least one site. Cadmium and Zn also exceeded recommended clean-up guidelines at Site 12, where the very high Pb levels also were detected (Table 7). All the elements analysed in the 1986 soil survey were proportionally elevated in the 5 to 10 cm depth at Site 12. There was no consistent contamination gradient for Cd, Cr, Ni and Zn, even though some elevated soil levels were detected at a few of the sites close to ERL.

The Cr data were particularly anomalous. Chromium soil concentrations exceeded the ULN guideline of 50 ppm at four sites. These four locations included Site 13, only 360 m NE of ERL, where elevated concentrations of other elements had been detected; however, the remaining three sample sites were randomly scattered across Port Hope. The highest Cr concentration was 104 ppm, more than twice the ULN guideline, and this occurred in the 10 to 15 cm depth at Site 16, more than 1 km NE of ERL (Table 8). This site was at the edge of a lawn in an established neighbourhood, where there were no signs of recent disturbance and no apparent local industrial sources. Sample replication was acceptable and Cr levels in the other two sample depths were similarly elevated. However, Cr concentrations were well below the recommended residential clean-up guideline of 1000 ppm at all sites.

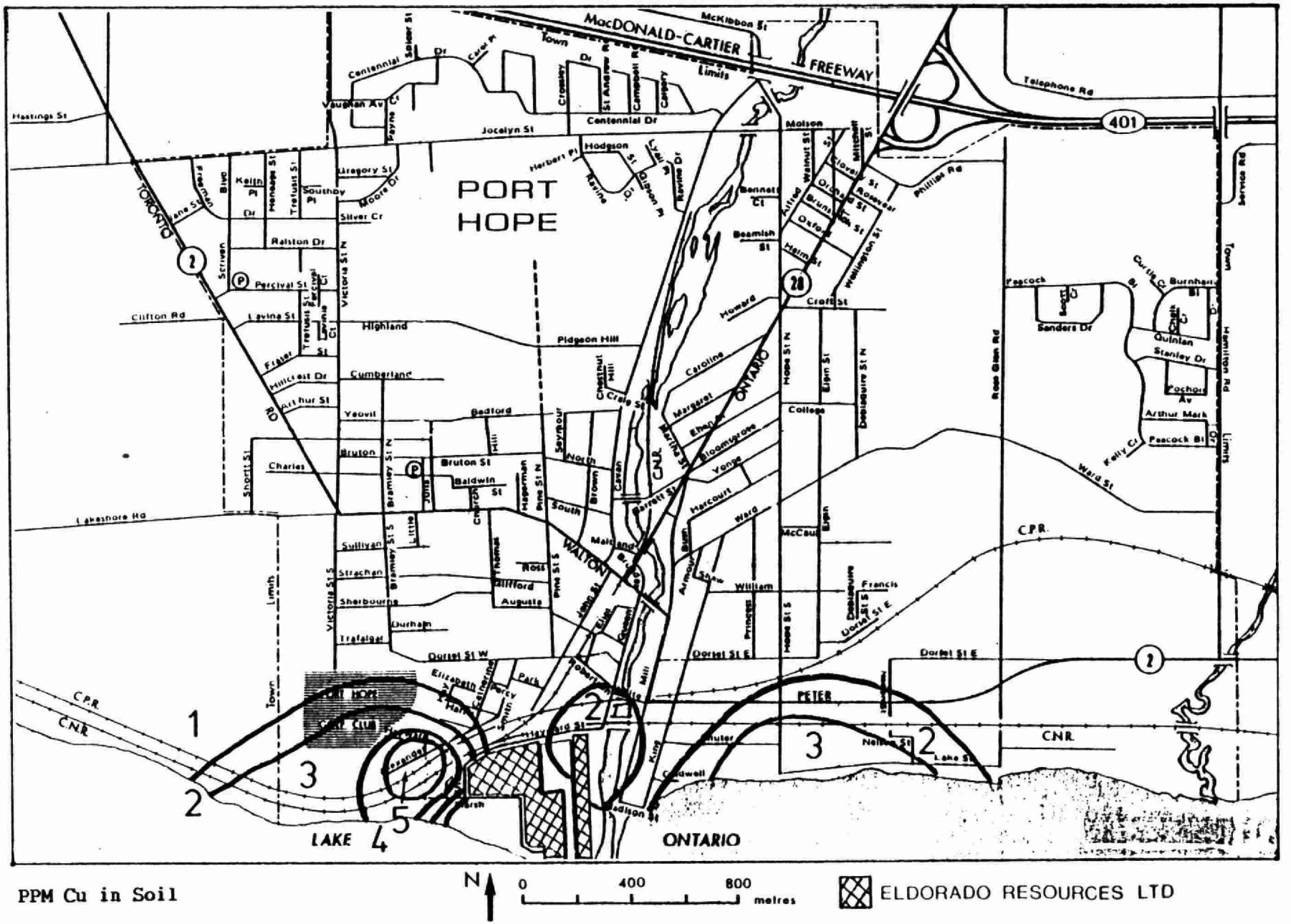
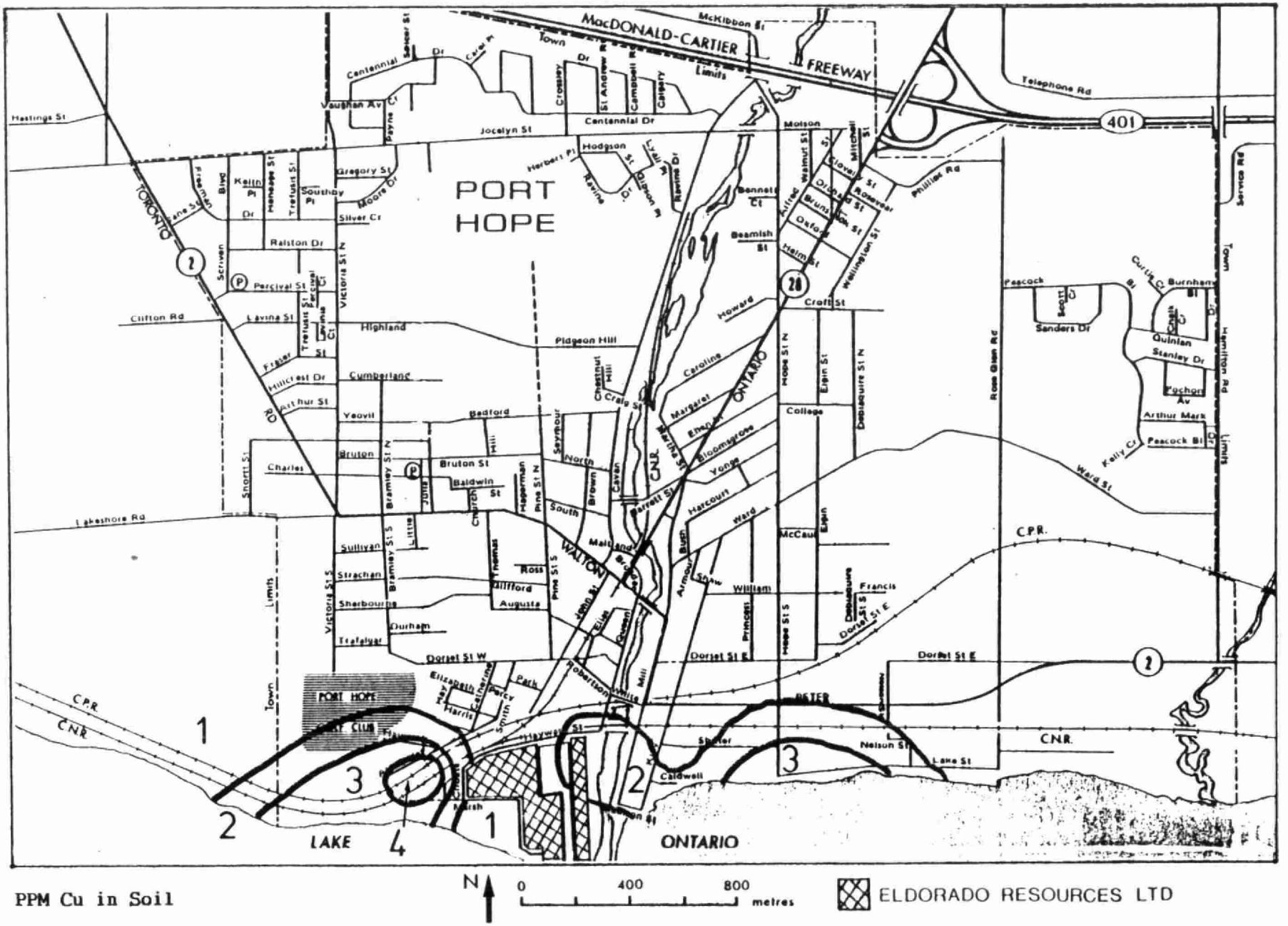


Figure 15: Contours of Copper in Soil, as Estimated by SYMAP (1986, 0-5 cm depth).



PPM Cu in Soil

1 <60
2 60-100
3 101-200
4 201-300
5 >300

Figure 16: Contours of Copper in Soil, as Estimated by SYMAP (1986, 5-10 cm depth).

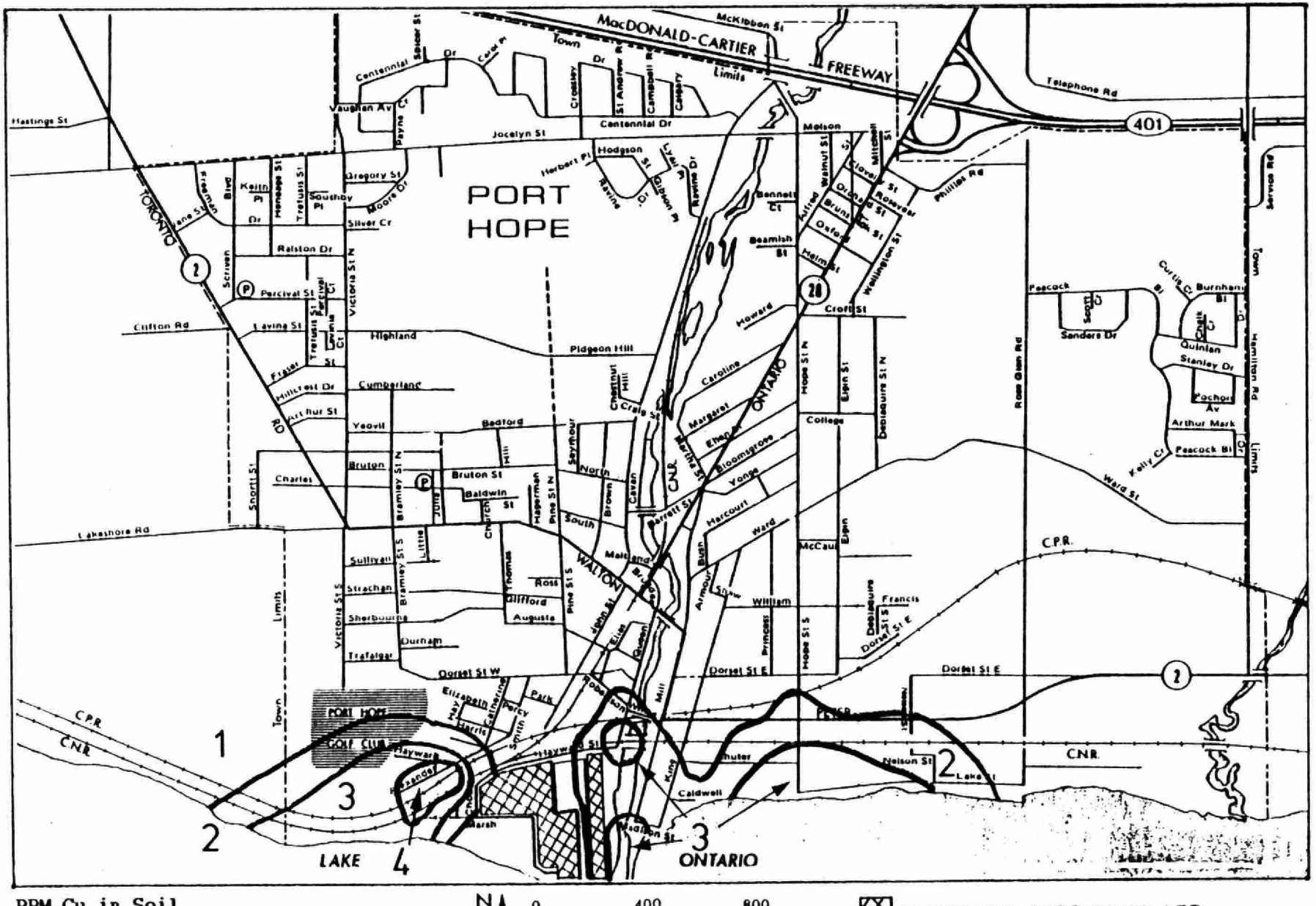


Figure 17: Contours of Copper in Soil, as Estimated by SYMAP (1986, 10-15 cm depth).

Table 9 (p. 24) summarizes the mean concentration of the eight elements included in the 1986 soil survey by the three sample depths and lists the number of sites which exceeded Phytotoxicology Section guidelines.

10. Results of the 1986 Grass Survey

In 1986, triplicate grass samples were collected from each of the 36 soil sites. Most of the samples were lawn grass from the edge of the residential properties and municipal parks. The grass was processed oven dried and not washed, and analysed for total U, As, Cd, Cr, Cu, Ni, Pb and Zn.

The results of these analyses are summarized in Table 10. The data are compared with ULN guidelines for rural grass samples (there currently are no urban ULNs for grass). Of those eight elements, only U and As displayed a consistent contamination gradient relative to distance and direction from ERL. The two highest concentrations for both elements occurred at the same two sites (Site 3, 140 m SSW and Site 8, 280 m SSW).

In contrast to the other metal data, there was a clear concentration gradient of U in grass in relation to ERL. The U levels decreased rapidly with increasing distance from the source to about 500 m, beyond which the concentration gradient was much more gradual. A ULN has not been established for U in grass, although the literature data summarized in Table 2 suggest that natural background concentrations are highly species-specific but that the upper range limit is about 0.04 ppm. All but one of the 36 sites had grass U levels higher than 0.04 ppm. The four most distant sample sites in all directions had grass U concentrations ranging from 0.03 to 0.09 ppm. By comparison, at least 2/3 of the Port Hope town limits, an area of about 9 km^2, had grass U concentrations greater than 0.10 ppm.

Table 10: Results of Grass Chemical Analysis - Samples Collected from the Same Sites as the 1986 Soil Survey

Site No.	Distance & Direction from ERL	Metal Concentration (ppm)* U	As	Cd	Cr	Cu	Ni	Pb	Zn
1	360 m ESE	1.99	0.44	<0.1	<1	7	2	2	24
2	840 m ENE	1.44	0.03	<0.1	<1	**9**	<1	<1	29
3	140 m SSW	23.2	0.94	0.1	1	7	1	4	**78**
4	240 m NW	0.47	0.32	<0.1	1	**8**	2	<1	29
5	400 m NNE	0:24	0.19	<0.1	<1	**10**	2	2	39
6	660 m NNE	0.69	0.10	0.2	<1	**8**	<1	3	23
7	280 m WSW	1.23	0.83	<0.1	<1	4	<1	<1	35
8	280 m SSW	6.05	0.95	<0.1	5	**8**	3	<3	27
9	400 m SSE	1.16	0.38	<0.1	2	**9**	1	<1	25
10	100 m NW	0.75	0.14	0.2	<1	**8**	1	2	13
11	200 m NNE	1.46	0.79	<0.1	<1	3	<1	2	13
12	320 m NE	0.82	0.26	<0.1	<1	**9**	2	6	38
13	360 m NE	1.96	0.60	<0.1	<1	**15**	2	1	**47**
14	720 m ENE	1.75	0.30	<0.1	<1	7	<1	<1	28
15	820 m NE	0.37	0.19	<0.1	<1	**11**	2	3	32
16	1080 m NE	0.27	0.09	0.3	<1	**9**	1	3	29
17	2060 m NE	0.42	0.07	<0.1	<1	6	<1	<1	24
18	3000 m NE	0.10	0.05	0.1	<1	**10**	<1	<1	30
19	4160 m NE	0.09	<0.03	<0.1	<1	1	<1	2	6
20	1100 m ENE	0.25	0.09	<0.1	<1	5	<1	2	11
21	1780 m ENE	0.77	0.09	<0.1	5	6	3	5	31
22	2960 m ENE	0.75	0.06	<0.1	<1	6	1	5	23
23	960 m N	0.13	0.04	0.2	1	**11**	2	7	**47**
24	1420 m N	0.13	0.16	<0.1	<1	**11**	1	4	35
25	1700 m NNE	0.13	0.07	<0.1	<1	**11**	1	7	**43**
26	2700 m N	0.03	0.11	<0.1	<1	**10**	<1	2	28
27	520 m N	0.22	0.23	<0.1	<1	6	<1	5	30
28	1180 m NNW	0.19	0.10	<0.1	<1	6	<1	3	32
29	620 m NW	0.36	0.22	<0.1	1	**12**	<1	4	40
30	460 m NNW	0.15	0.29	<0.1	<1	**9**	<1	1	40
31	840 m WNW	0.50	0.05	<0.1	<1	**10**	<1	<1	33
32	1560 m WNW	0.06	0.05	<0.1	<1	6	<1	1	22
33	980 m NW	0.12	0.33	<0.1	<1	**13**	<1	1	**44**
34	1060 m NW	0.09	0.77	<0.1	<1	**9**	<1	3	3.8
35	1580 m NNW	0.06	0.10	<0.1	<1	4	<1	<1	18
36	2800 m NW	0.07	0.14	<0.1	<1	7	<1	5	25
Phytotoxicology Upper Limit of Normal** (exceedances in bold)		NE	NE	0.5	5	7	5	20	40

* Parts per million, oven dry wt., mean of triplicate samples
** ULN described in report (based on samples from rural areas)
NE Not Established

Figure 18 is a SYMAP of U in grass. Uranium concentrations greater than 1.0 ppm (maximum 23.2 ppm) were predicted slightly more than 1 km E and W of ERL. The maximum concentration was more than 250 times higher than the Port Hope area background of approximately 0.09 ppm.

An ULN guideline for As in Southern Ontario grass samples has not been established due to a very high proportion of "non-detectable" results for background samples. The maximum As level in grass in Port Hope averaged 0.95 ppm, about 30 times higher than the minimum concentration of 0.03 ppm. These data confirm the results of the maple foliage survey which indicated that ERL is a current source of As emissions.

The ULN guidelines for Cd, Cr, Ni and Pb in grass were not exceeded at any of the 36 samples sites, nor were contamination gradients evident for any of these elements.

The ULN (rural) for Zn in grass was exceeded at five sites. Even though the maximum concentration of 78 ppm occurred at Site 3, which at 140 m SSW, is the second closest site to ERL, there was no consistent contamination gradient to implicate ERL as an atmospheric source. The levels tended to be higher in the downtown area, which is not uncommon, even for a fairly small urban community.

The Cu data were somewhat anomalous. Copper concentrations in grass exceeded the ULN (rural) of 7 ppm at 21 of the 36 sample sites. Although the maximum Cu concentration was detected at Site 13 (15 ppm, 360 m NE), which is close to and directly downwind of ERL, grass Cu levels only marginally lower and still exceeding the ULN occurred at several other sample sites with no relation to distance or direction from ERL. Overall, there was no consistent Cu concentration gradient relative to ERL or other industrial sources in Port Hope.

The contamination gradients predicted by the SYMAP program for U in grass (Figure 18) correlate well with the distribution of U in soil (Figures 6, 7 and 8). Correlation coefficients for U in grass vs. in soil at all three soil sampling depths were highly significant ($p<0.01$). The

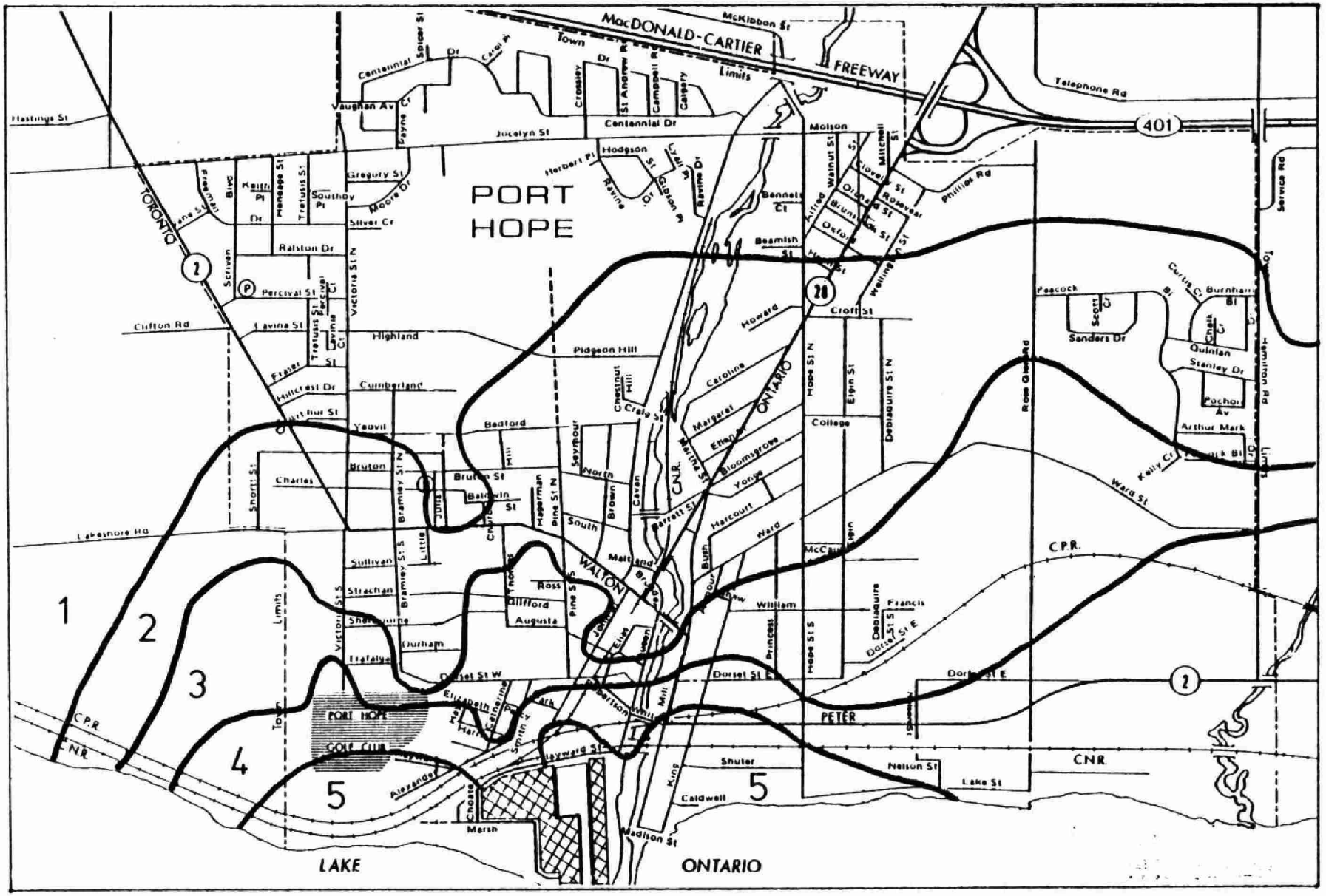


Figure 18: Contours of Uranium in Grass, as Estimated by SYMAP (1986).

highest correlation coefficient was log U in grass vs log U in soil (5 to 10 cm depth) ($r = 0.838$, $p < 0.01$). The data were log transformed because neither the grass U nor the soil U were normally distributed and the absolute differences were very large. This correlation is graphically illustrated in Figure 19.

Moss bag surveys conducted in Port Hope in 1982 and 1984 clearly identified ERL as a source of atmospheric U emissions. The annual maple foliage collection results corroborate these findings, although on a limited scale. The 1986 grass survey confirms that ERL is a current source of atmospheric U emissions and that these emissions result in terrestrial biomass U loadings which far exceed normal background levels.

11. 1987 Soil Assessment Survey

The 1986 soil survey confirmed that the greatest degree of contamination occurred in the south central section of Port Hope in the general area of the river mouth and the rail lines. In addition to residential and commercial properties, the publicly accessible areas are used by a great number of people who fish the Ganaraska River during the seasonal rainbow trout run. There are also three municipal parks located in the zone of highest soil contamination: 1) south of Madison St. and east of the marina, 2) the beach south of the train station and west of the Port Hope water pumping station and 3) the vicinity of the town hall, east and west of Queen St.

In 1987, surface soil samples were collected from 18 of the original (1986) sites and from an additional 23 locations. The new sample sites were in the area of public use, where the 1986 concentrations were elevated, and where sample replicate variability was very high. Figure 20 illustrates the locations of all additional sample sites in 1987 as well as 15 of the 18 1986 sites which were resampled. The objective of the intensified 1987 soil survey was to more accurately define the area of elevated concentrations, specifically as this related to residential and public use areas.

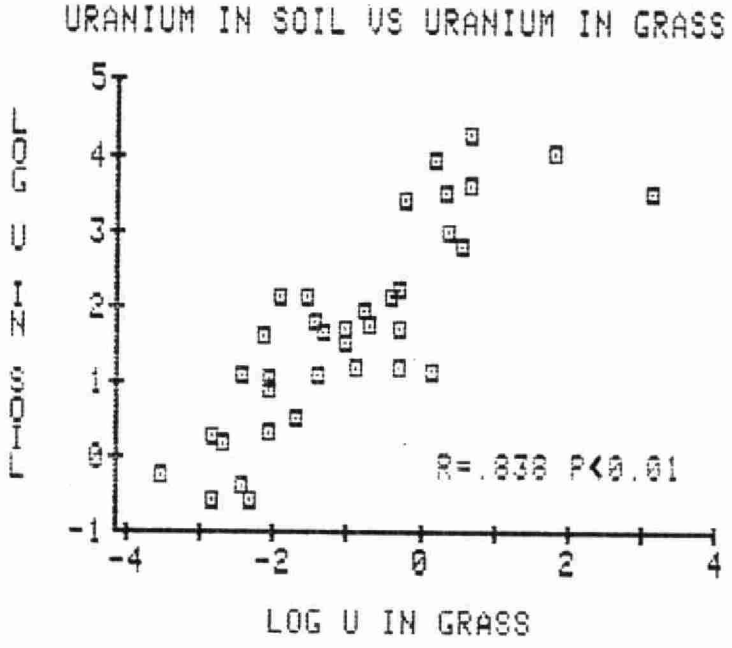


Figure 19: Relationship Between Uranium in Grass and Uranium in Soil from the 5-10 cm Sampling Depth (data are log transformed).

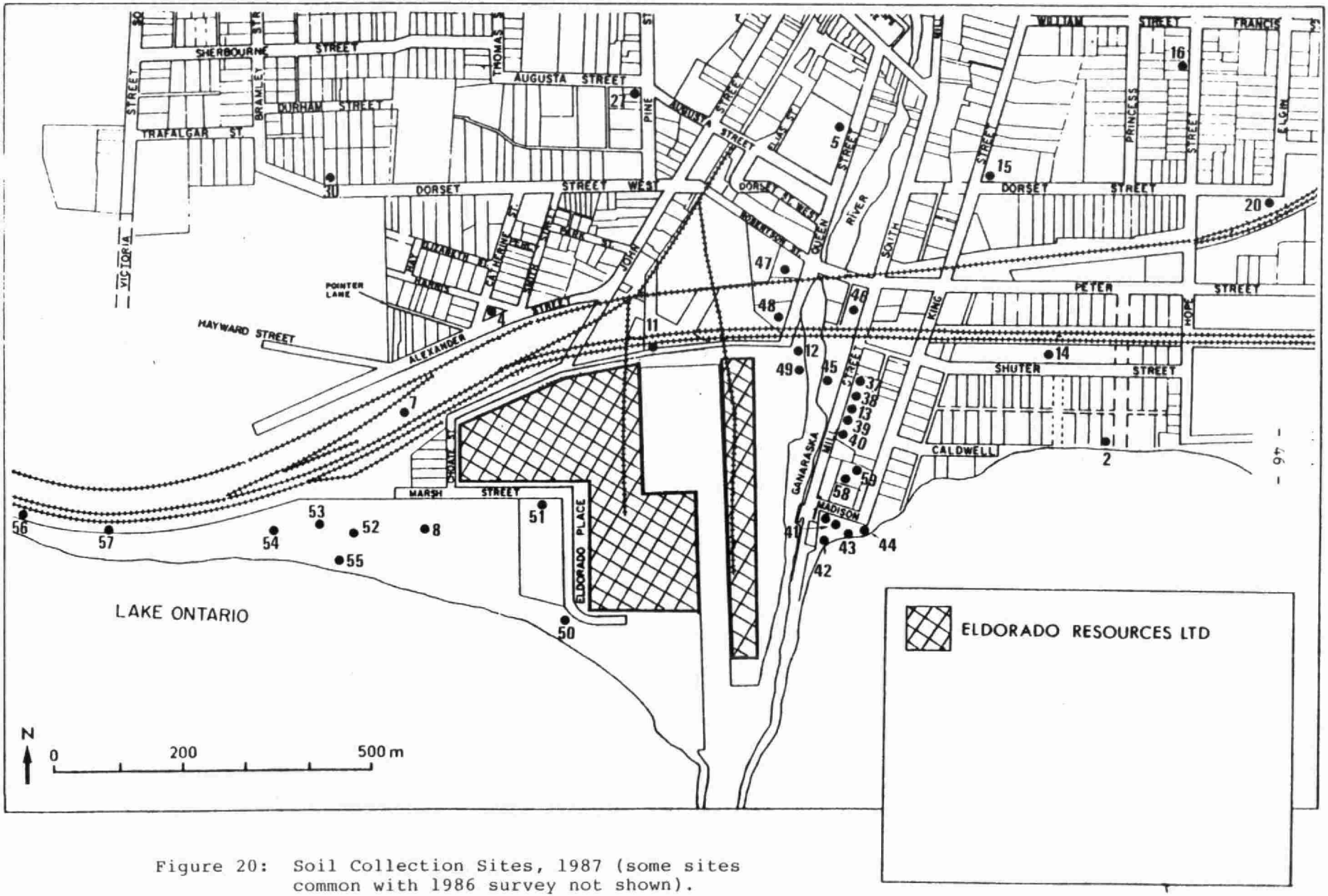


Figure 20: Soil Collection Sites, 1987 (some sites common with 1986 survey not shown).

In addition to U, As, Cd, Pb, Zn, Ni, Cu and Cd, the 1987 samples were analyzed for total iron (Fe), cobalt (Co), chromium (Cr), antimony (Sb) and selenium (Se). Arrangements also were made with the Radiation Protection Lab of the Ontario Ministry of Health to determine the activities of ^{238}U, ^{228}Th, ^{226}Ra, ^{228}Ra, ^{40}K and ^{210}Pb in soil from 23 of the 41, 1987 sample sites.

The elemental analyses and the radionuclide data are summarized in Tables 11 and 12 respectively. In Table 11 Sites 1 through 33 correspond to the 1986 sample locations of the same number. The sites numbered consecutively from 37 to 59 are the 1987 sample locations. All soil samples collected in 1987 were from the 0 to 5 cm depth.

11.1 Results of Soil Uranium Analysis - 1987

A SYMAP of U in soil based on the 1987 survey results is shown in Figure 21. The series of SYMAPs of the 1987 data are a more accurate delineation of actual soil concentrations because they were generated from a larger number of sample sites from a smaller geographical area. Figure 21, the 1987 U SYMAP, compares very well with Figure 6, the 1986 soil U SYMAP. A notable exception is that the additional sampling in 1987 showed that the higher soil U concentrations are not quite as extensive as depicted in 1986. The 1987 data confirm that the highest soil U concentrations are found immediately downwind (east) of ERL at the base of Mill and King Streets. In fact, the maximum U level (135 ppm) was detected in the small municipal park south of Madison St. and east of the marina. However, the concentrations in this park varied considerably, although they were all well above background. Soil in the immediate area of the children's play set (i.e. Site 46, collected under the swings) contained 27 ppm U.

The soil U concentrations in the beach park southwest of Marsh St. also were highly variable. However, the sandy area around the children's play set and other sites within the park which had been recently landscaped had

Table 11: Results of Soil Chemical Analysis from the 1987 Soil Survey (0 to 5 cm Sampling Depth).

Site No.	U	As	Pb	Cu	Sb	Ni	Zn	Fe	Cd	Co	Cr	Se
1	**70**	14	65	18	**27**	11	87	14500	0.2	0.7	29	0.40
2	**47**	5.4	245	**104**	**340**	37	345	**38500**	0.1	9	37	0.22
4	**17**	17	81	18	4.4	8	102	11000	0.4	5	18	0.27
5	**8**	16	98	20	4.5	12	103	16000	0.3	8	34	0.30
7	**88**	**120**	205	**225**	**25**	37	290	24000	1.1	14	24	0.76
8	**96**	11	39	14	0.6	6	83	13500	0.6	4	17	0.17
11	**23**	13	235	81	**15**	29	140	18500	0.5	0.1	23	0.27
12	**48**	**58**	**915**	**180**	**59**	**130**	355	**45500**	1.3	**38**	36	0.61
13	**48**	**82**	215	64	**43**	21	225	15000	0.6	0.2	48	1.0
14	**15**	20	33	18	7.5	11	87	14000	0.4	6	28	0.32
15	**14**	19	106	21	3.8	12	115	16000	0.3	9	26	0.44
16	**8**	5.2	71	19	0.7	13	79	17000	0.4	7	**95**	0.22
20	**11**	10	81	23	2.4	18	104	22000	0.5	10	33	0.23
25	2	1.9	57	15	0.3	8	81	16000	2.1	5	43	0.12
27	**9**	15	220	29	5.7	9	110	12500	0.4	0.7	21	0.80
30	**9**	16	280	16	5.4	9	170	14000	0.4	6	20	0.36
32	3	3.4	25	13	0.7	8	60	14500	0.1	5	**67**	0.13
33	4	8.7	70	12	4.6	7	71	13000	0.2	5	28	0.11
37	**48**	18	115	68	**15**	18	115	16000	0.6	12	25	0.38
38	**32**	**43**	150	47	**39**	18	155	14000	0.3	10	43	0.41
39	**34**	**34**	170	47	**38**	16	170	16000	0.5	10	46	0.50
40	**50**	**24**	99	32	**26**	15	107	16000	0.3	10	43	0.32
41	**14**	3.5	20	13	4.6	9	45	13000	0.3	6	26	0.17
42	**79**	4.1	37	12	**12**	10	53	12500	0.2	6	30	0.23
43	**135**	3.1	36	13	**10**	10	59	11500	0.3	6	26	0.15
44	**27**	3.5	29	15	6.5	10	51	14500	0.4	6	27	0.21
45	**24**	3.2	57	26	**25**	8	99	12500	0.4	5	18	0.22
46	**52**	7.8	190	27	**8.9**	13	97	14500	0.3	7	22	0.09
47	**29**	6.8	270	41	**13**	12	145	13000	1.7	6	25	0.17
48	**23**	12	155	36	**50**	14	125	12000	0.4	8	19	0.07
49	2	1.9	**505**	61	**1300**	42	**1300**	**40500**	0.3	22	41	0.30
50	**22**	3.2	12	7	3.2	7	32	16500	0.2	5	24	0.07
51	**11**	4.8	9	12	1.3	11	48	17000	0.2	8	28	0.29
52	0.7	3.1	10	5	0.5	7	33	13000	0.2	5	24	0.11
53	3	2.2	22	9	0.04	10	36	15000	0.9	8	29	0.28
54	**28**	1.8	6	10	0.02	8	42	14000	0.2	6	27	0.30
55	2	2.1	1	3	0.02	4	17	19500	0.1	3	17	0.02
56	2	1.4	4	4	0.04	4	18	8350	0.1	3	14	0.02
57	2	**39**	42	85	7.1	26	105	18500	0.2	16	25	0.37
58	**100**	**81**	**515**	80	**44**	23	365	17500	0.7	16	29	0.78
59	**77**	**110**	395	75	**38**	21	250	16000	0.8	13	26	0.50
ULN	5	20	500	100	8	60	500	35000	4	25	50	2
CUG	NE	25	500	200	25	200	800	NE	4	50	1000	2

* Parts per million, air dried wt., mean of duplicate samples, 0-5 cm depth.

ULN Phytotoxicology Upper Limit of Normal guideline, defined in report (ULN for U is tentative) (exceedances in bold)

CUG Phytotoxicology recommended residential clean-up guidelines, described in report (exceedances underlined)

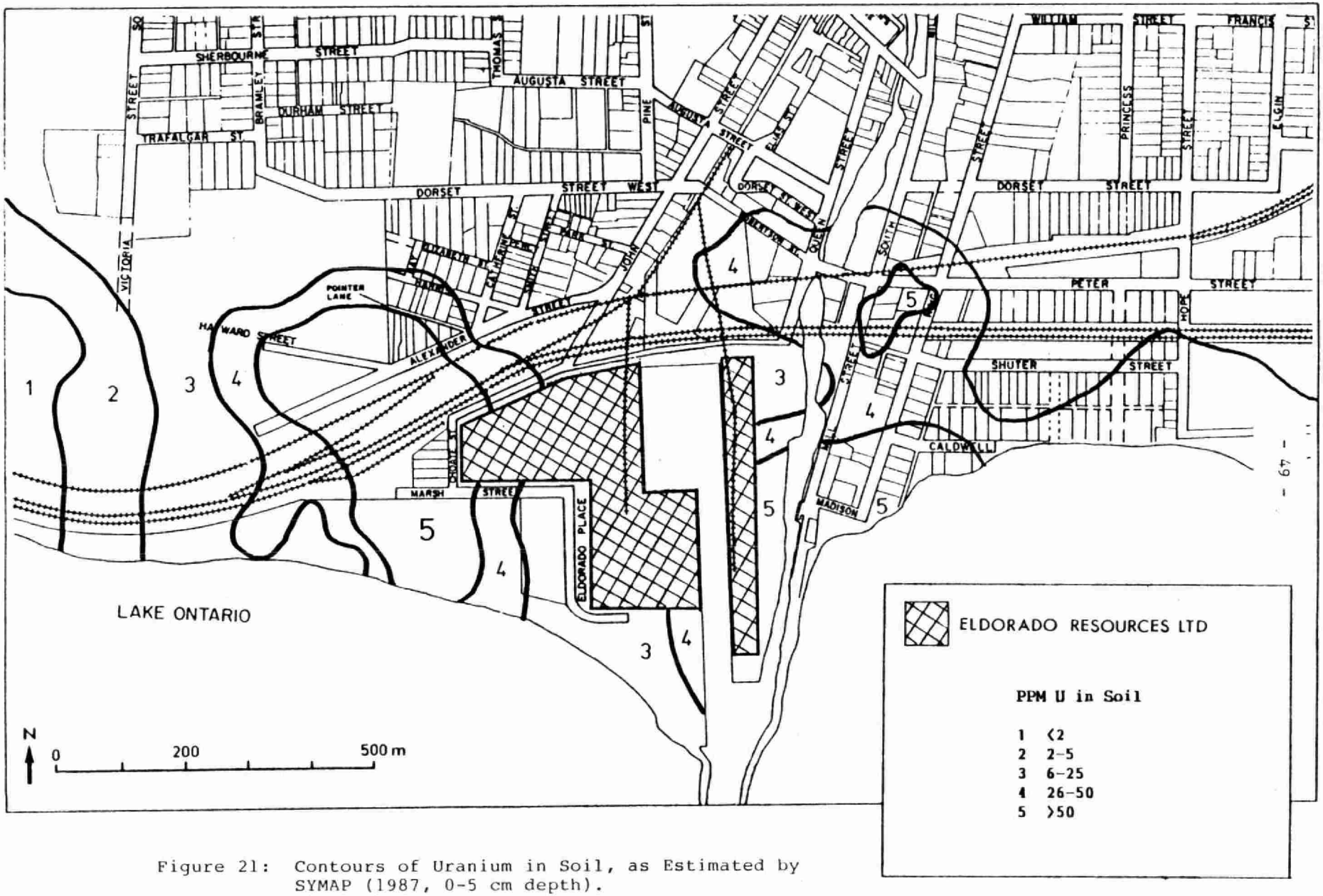


Figure 21: Contours of Uranium in Soil, as Estimated by SYMAP (1987, 0-5 cm depth).

soil U levels of 3 ppm or lower, compared with 96 ppm and 24 ppm at the sites east and west of the park respectively.

11.2 Results of Soil Pb Analysis - 1987

Figure 22 displays the 1987 SYMAP for soil Pb contamination. It can be compared with Figure 12, which illustrates the contours of soil Pb as determined in the 1986 survey. The more intensive 1987 data confirm that soil Pb contamination (levels greater than the 500 ppm residential clean-up guideline) is confined to two small specific locations. These are: 1) the area along the west bank of the Ganaraska River immediately south of the railway, and 2) the residential property adjacent to Madison St. The highest Pb concentration detected in the 1987 survey was 915 ppm, from the area west of the river (Site 12). In 1986, surface soil at this site contained several thousand ppm Pb. Therefore, although these data confirm elevated Pb levels from 1986, the significant contamination appears to be isolated in small, specific locations, and, based on the 1986 data, is present also in sub-surface soil depths.

The additional sites employed in the 1987 survey modified the Pb contours along the lakeshore to the east and west of ERL. The soil Pb levels determined in this area in 1987 were somewhat lower than those depicted in the 1986 SYMAP. The two parks in this area have relatively low soil Pb concentrations of less than 40 ppm.

11.3 Results of Soil As Analysis - 1987

The SYMAP which delineates As soil concentrations based on the 1987 data is displayed as Figure 23. This can be compared with the 1986 soil As SYMAP (Figure 9). The general pattern of As contamination is very similar in both SYMAPs, except that the area of high soil As (greater than the 25 ppm residential clean-up guideline) is smaller and better defined because of the enhanced sampling resolution in 1987. Also, like Pb, the actual As soil levels along the lakeshore are somewhat lower than the (1986) computer generated contours. The two lakeshore parks had consistently low

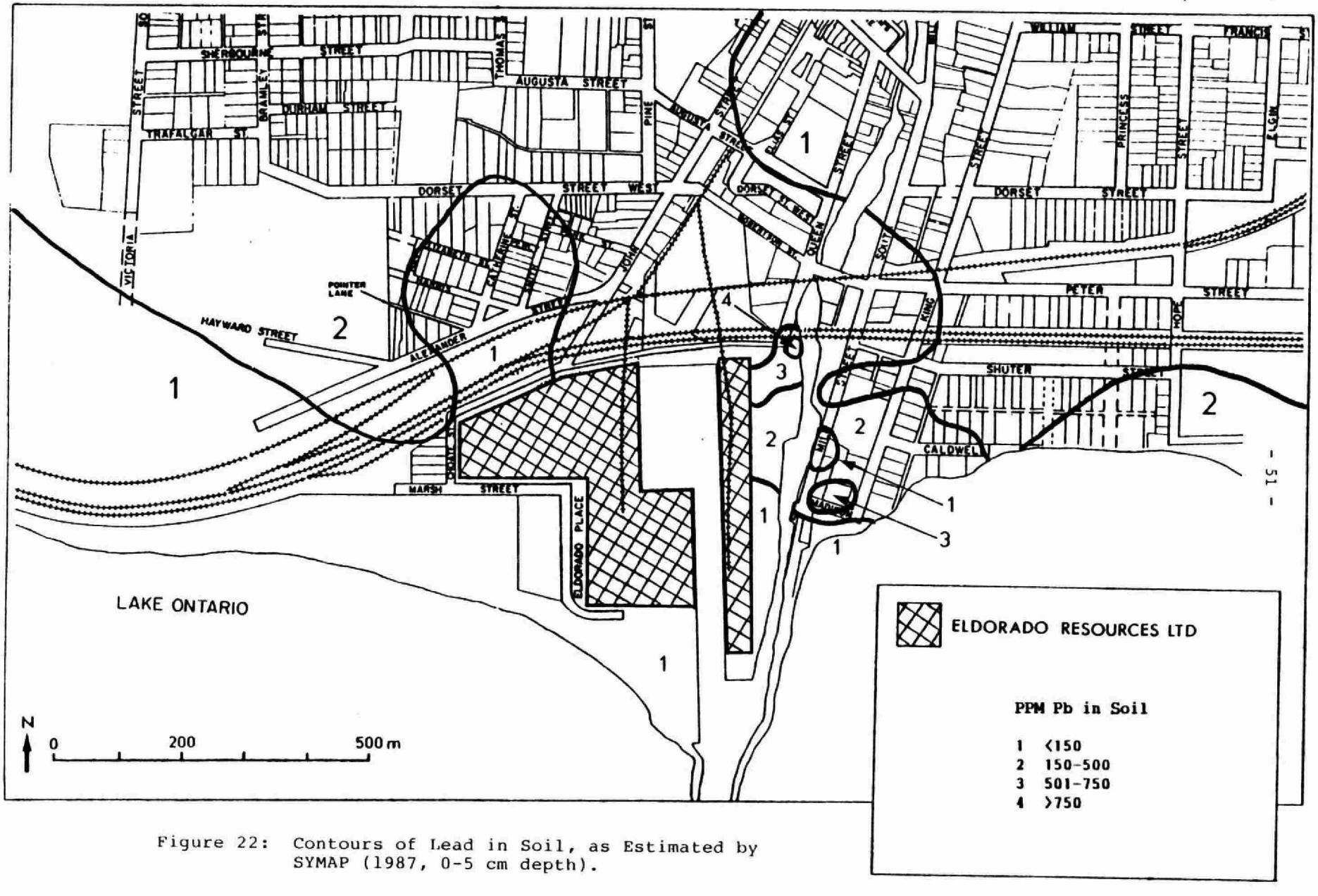


Figure 22: Contours of Lead in Soil, as Estimated by SYMAP (1987, 0-5 cm depth).

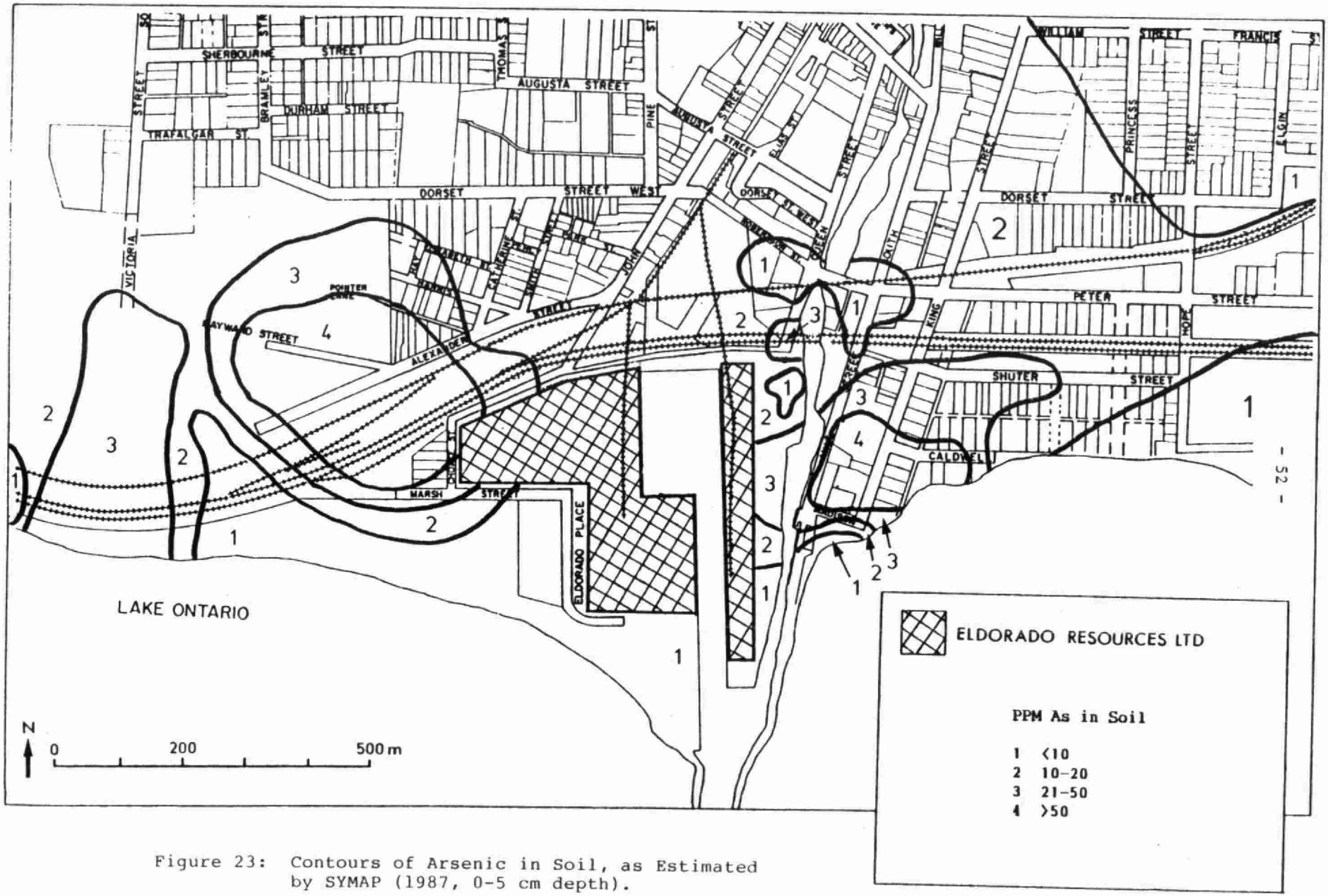


Figure 23: Contours of Arsenic in Soil, as Estimated by SYMAP (1987, 0-5 cm depth).

soil As concentrations. The concentration gradient in these areas was steep, however, as soil As levels in excess of 50 ppm occurred immediately north of both parks.

The maximum As level in 1987 was 120 ppm which was detected in soil at Site 7 (Table 11), near the Port Hope railway station. Soil As concentrations only marginally lower (110 ppm) occurred on the residential property at the corner of Madison and King Streets.

11.4 Results of Soil Cu Analysis - 1987

The 1987 Cu SYMAP is shown in Figure 24. Figure 15 is the comparative 1986 SYMAP for Cu in soil. The two SYMAPs have very similar concentration contours. Again, the 1986 SYMAP tends to slightly enlarge the highest concentration zones, but this is corrected in the 1987 SYMAP. The 1987 survey data confirm that soil Cu concentrations in the southern portion of Port Hope are highly variable but that levels above the ULN guideline of 100 ppm (zones 3 to 5 in Figure 24) occurred in three separate areas. Two of these are the same general area where elevated soil U, As and Pb concentrations were detected; i.e. around the railway station, and the west bank of the Ganaraska River immediately south of the tracks. The third area was in the vicinity of the south end of Hope St. Soil Cu levels which were elevated but did not exceed Phytotoxicology guidelines also were encountered on the residential properties adjacent to Madison St.

In addition to defining the areas of soil Cu contamination more precisely, the 1987 survey also confirmed the areas where soil Cu levels were not elevated. As illustrated in Figure 24, the shoreline in the vicinity of the two parks and the municipal open areas around the town hall had soil Cu concentrations which are normal for an urban environment.

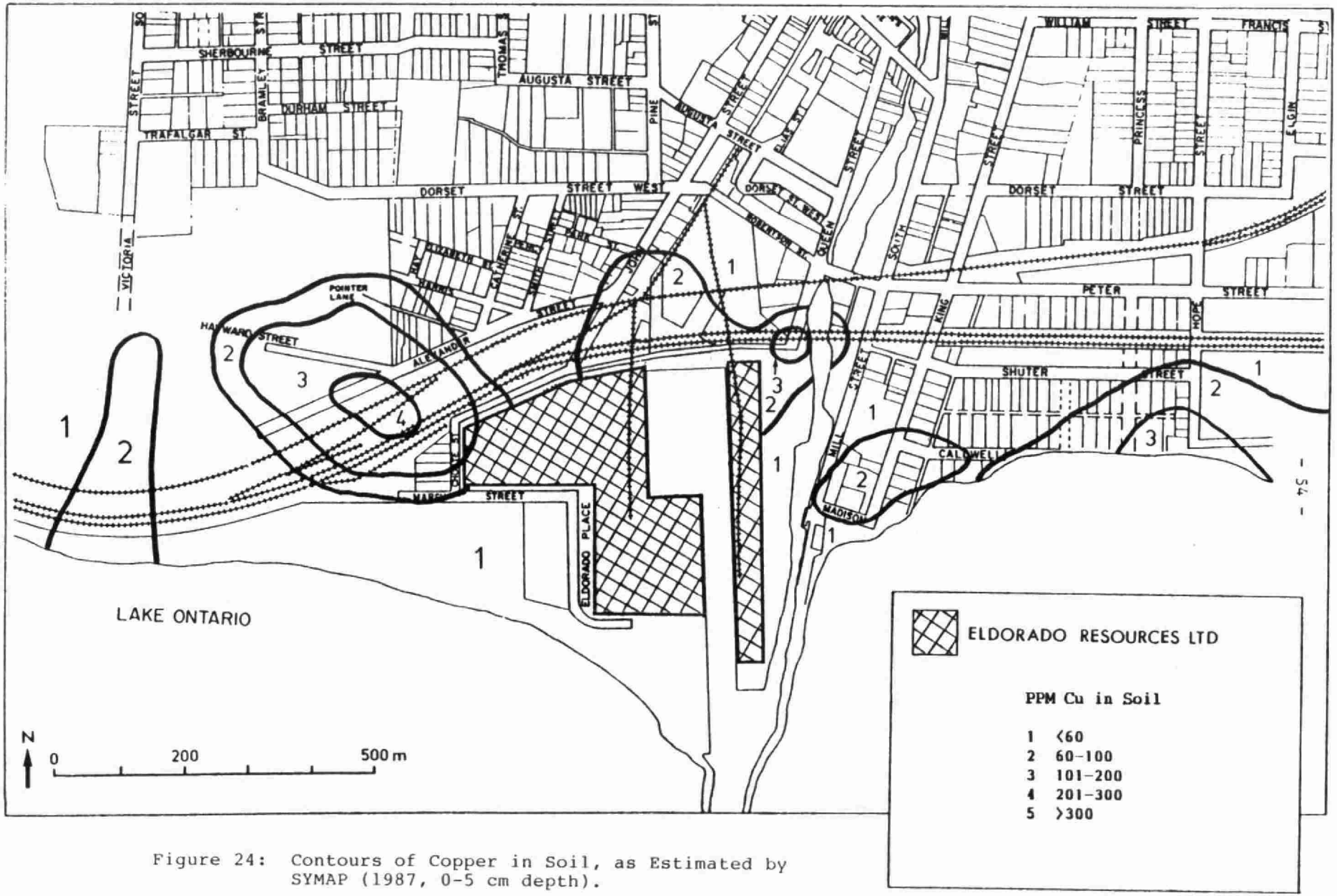


Figure 24: Contours of Copper in Soil, as Estimated by SYMAP (1987, 0-5 cm depth).

11.5 Results of Soil Sb Analysis - 1987

Figure 25 illustrates the Sb concentration gradient in soil as contoured by the SYMAP program. Soil samples collected in 1986 were not analysed for Sb; therefore, a SYMAP for the entire Port Hope area is not available for comparison. The Phytotoxicology ULN guideline for Sb in soil in an urban environment is 8 ppm. This level was exceeded at 19 of the 41 sites from which soil was collected in 1987 (Table 11). At some of these sites the exceedances were substantial. The soil at Site 7 by the Port Hope railway station averaged 25 ppm Sb, slightly more than three times the ULN. Soil at Site 2 near the lakeshore bluff at the south end of Hope St. averaged 340 ppm Sb, over 42 times higher than the ULN guideline. The maximum soil Sb concentration detected was 1300 ppm, which is more than 160 times the urban ULN. This was encountered at Site 49, adjacent to the west bank of the Ganaraska River just south of the railway overpass. However, this exceptionally high Sb level was very site-specific, as sample sites within 100 m in all directions had soil Sb concentrations which ranged from 9 ppm to 43 ppm.

Concentrations of Sb below the ULN were consistently found beyond 700 m NW and N of ERL. However, soil Sb concentrations to the east of the source were elevated at much greater distances. Soil in the vicinity of the municipal park by the town hall averaged 4.5 ppm Sb whereas the beach park west of ERL had soil Sb levels which did not exceed 0.5 ppm. By comparison, soil Sb concentrations in the park immediately east of the marina by Madison St. ranged from 4 ppm to 12 ppm.

11.6 Results of Soil Ni, Zn, Fe, Cd, Co, Cr and Se Analysis - 1987

The results of soil Ni, Zn, Fe, Cd, Co, Cr and Se analysis are also summarized in Table 11. SYMAPs were not prepared for these elements because contamination gradients were weak or elevated concentrations occurred at only a few sample sites. The soil Se and Cd concentrations did not exceed the respective ULN guidelines at any of the sample sites.

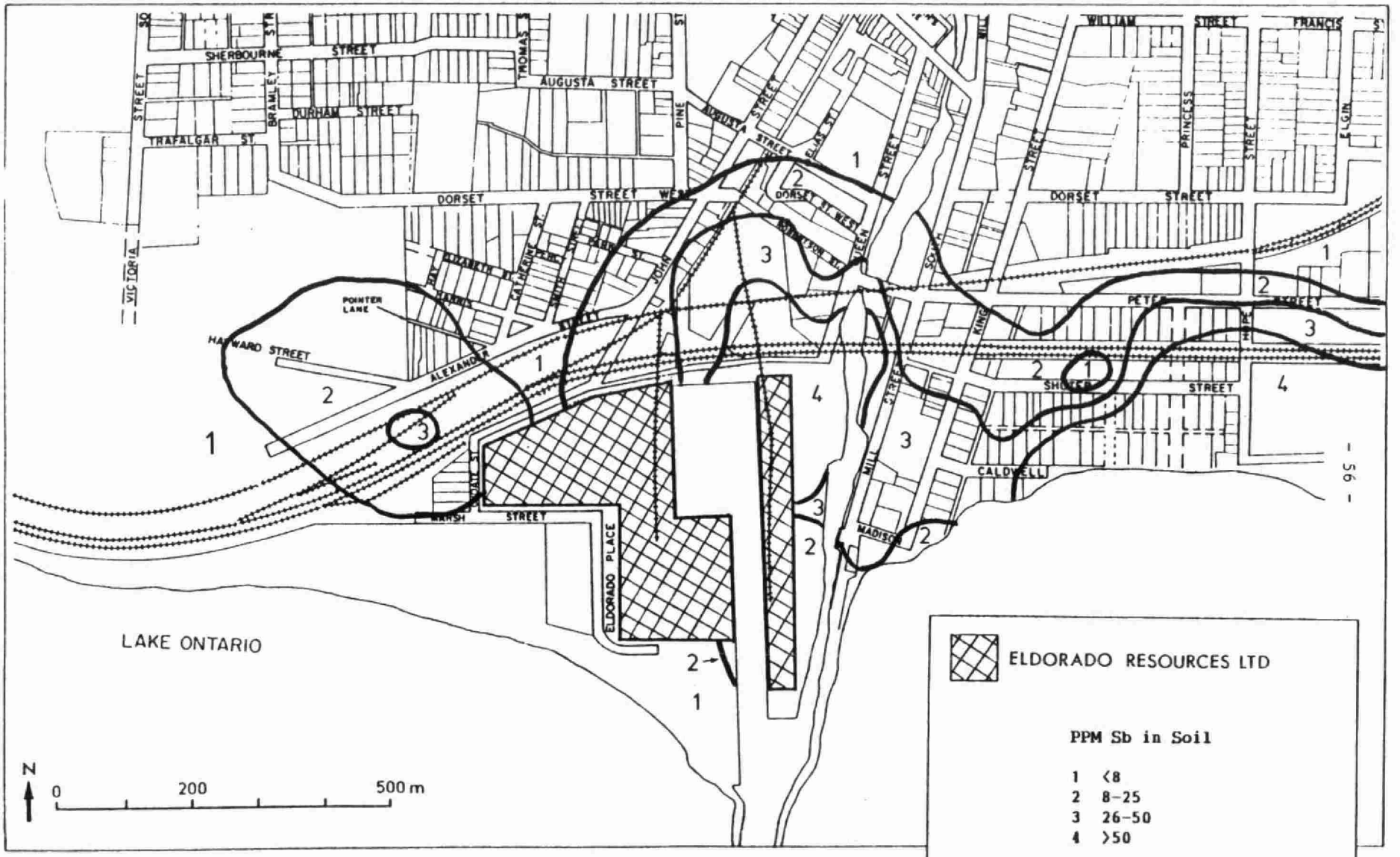


Figure 25: Contours of Antimony in Soil as Estimated by SYMAP (1987, 0-5 cm depth).

Although the highest levels of these two elements tended to occur in the same areas as the elevated U, As, Pb and Sb levels, the gradient elsewhere was inconsistent.

The Ni, Zn, and Co ULN guidelines were each exceeded at one site. For Ni and Co this was Site 12, where so many other exceedances occurred. The Zn exceedance was Site 49, which is immediately south of Site 12 and along the same area of the river bank. The Fe ULN was exceeded at three sites (No's 2, 12 and 49), again in areas where exceedances of many elements were frequent. Soil Cr concentrations exceeded the ULN at Sites 16 and 32. These levels are anomalously elevated. Chromium concentrations in soil in Port Hope bear no relation to known industrial sources, either current or historical.

12. Results of 1987 Soil Radionuclide Analysis

In 1987, surface soil (0 to 5 cm depth) was collected from 23 of the 36 sites sampled in 1986 and submitted to the Radiation Protection Laboratory of the Ontario Ministry of Health for limited radionuclide analysis. In this laboratory, 25g sub-samples were taken, sealed for 30 days and counted 60000 seconds on HPGe detectors to determine ^{238}U, ^{228}Th, ^{40}K, ^{226}Ra, ^{228}Ra and ^{210}Pb activities. The 23 sample sites were selected based on the gradient of inorganic soil contamination identified from the 1986 survey.

The results of the 1987 soil radionuclide analyses are summarized in Table 12. There are no Phytotoxicology ULN guidelines for radionuclides. Literature data for natural radionuclide background levels also are very limited, although references were found suggesting about 40 mBq/g for ^{238}U and ^{226}Ra and between 40 and 100 mBq/g for ^{210}Pb (Myrick et al., 1983). In 1987, the Peterborough MOE office co-ordinated a soil survey of Port Hope-area farm fields suspected of receiving U contaminated sewage sludge. In addition to U and other inorganic elements, the farm field samples were also analysed for some radionuclides. The average ^{238}U, ^{228}Th, ^{226}Ra, ^{228}Ra and ^{40}K levels encountered in these fields are listed at the bottom of Table 12. The Port Hope-area farm fields suspected of being treated

Table 12: Activities of Radionuclides in Surface Soil* from selected 1987 Soil Survey Sites

Site No.	Activity (mBq/g)** ^{238}U	^{226}Ra	^{210}Pb	^{228}Th	^{228}Ra	^{40}K
1	**1100**	**680**	**420**	<20	<20	460
2	**420**	**280**	100	<20	<20	160
3	**290**	**130**	**180**	<20	<20	460
4	**140**	**140**	**190**	<20	**20**	510
5	**100**	**60**	**120**	**20**	<20	530
7	**590**	**1500**	**110**	<20	<20	250
10	**90**	**90**	**1000**	<20	<20	590
11	**280**	**180**	**160**	<20	<20	490
12	**190**	**540**	**600**	<20	<20	370
13	**480**	**280**	**340**	<20	<20	490
14	**190**	**140**	**160**	<20	<20	540
15	**100**	**80**	80	<20	<20	570
17	**90**	**50**	60	<20	<20	**680**
19	**50**	**20**	**70**	**20**	<20	620
20	**110**	**60**	**100**	**30**	**30**	**690**
24	**70**	**100**	**150**	<20	<20	**640**
26	<20	20	40	<20	**20**	**770**
27	**120**	**190**	**160**	<20	**20**	460
31	**140**	30	**120**	<20	**20**	540
32	**60**	40	100	<20	<20	560
33	**50**	**140**	**210**	20	<20	480
34	**80**	**50**	**300**	<20	<20	540
35	**50**	**90**	**140**	<20	<20	580
Survey Mean	210	210	210	<20	<20	520
Area Farmland Mean	50	21	NA	<20	<20	630
Literature Background	≈40	≈40	≈ 100	NA	NA	NA

*0-5 cm

** 25 g samples sealed 30 days, counted 60000 seconds on HPGe detectors.

Exceedances of literature background (or farmland mean if no literature data) are in bold.

NA - not available

with ^{238}U contaminated sludge were comparable to the reported literature background (50 mBq/g - farm vs. 40 mBq/g - background). The ^{226}Ra activity of the farm fields averaged about one half literature background. The ^{210}Pb activity was not determined in the farm field samples and the ^{228}Th and ^{228}Ra activities were consistently below the detection limit of 20 mBq/g.

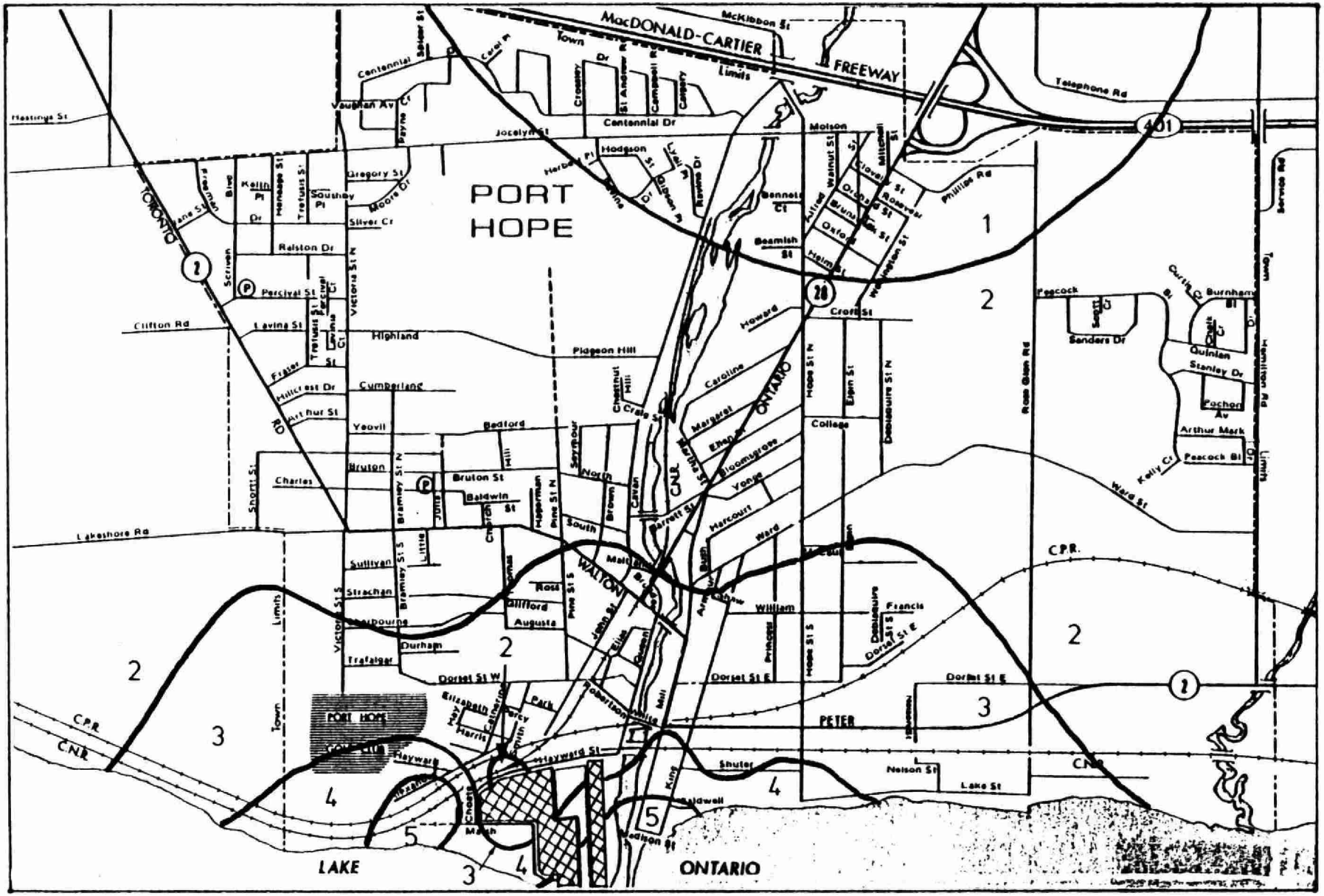
The ^{228}Th and ^{228}Ra activities were below or only marginally higher than the analytical detection limit of 20 mBq/g at all 23 of the 1987 Phytotoxicology radionuclide soil survey sites. The ^{40}K activities were highest farthest from the downtown area and ERL. Most of the sample sites had ^{40}K levels which compared favourably with the farm field samples ($\sim$ 520 mBq/g mean soil survey vs. 630 mBq/g mean farm fields).

The activities of the remaining three radionuclides, ^{238}U, ^{226}Ra and ^{210}Pb, had a clear contamination gradient suggestive of a source south of the railway tracks in the area of the river mouth. The highest activities consistently occurred in the same areas and at the same sites as the high inorganic levels, i.e., the area around the marina park by Madison St., the area of the railway tracks adjacent to the west shore of the Ganaraska River and the vicinity of the railway station between Hayward and Choate Sts.

13. SYMAPS of Radionuclide Distributions in Soil

Figure 26 is a SYMAP illustrating ^{238}U in soil. Activity levels of ^{238}U in soil exceeded the average activity found in Port Hope-area farm fields of 50 mBq/g at 19 of the 23 sites and exceeded the literature background of 40 mBq/g at all but one site. The maximum activity of 1100 mBq/g occurred adjacent to the marina south of Madison St., about 300 m east of ERL. Activities of greater than 500 mBq/g ^{238}U in soil were detected about the same distance west of ERL.

Figure 27 is a SYMAP illustrating ^{226}Ra contours in soil. The activity of ^{226}Ra in soil exceeded the literature background of 40 mBg/g at 19 of the



mBq/g 238U in Soil

1 <40
2 40-100
3 101-300
4 301-500
5 >500

Figure 26: Contours of ^{238}Uranium in Soil, as Estimated by SYMAP (1987, 0-5 cm depth).

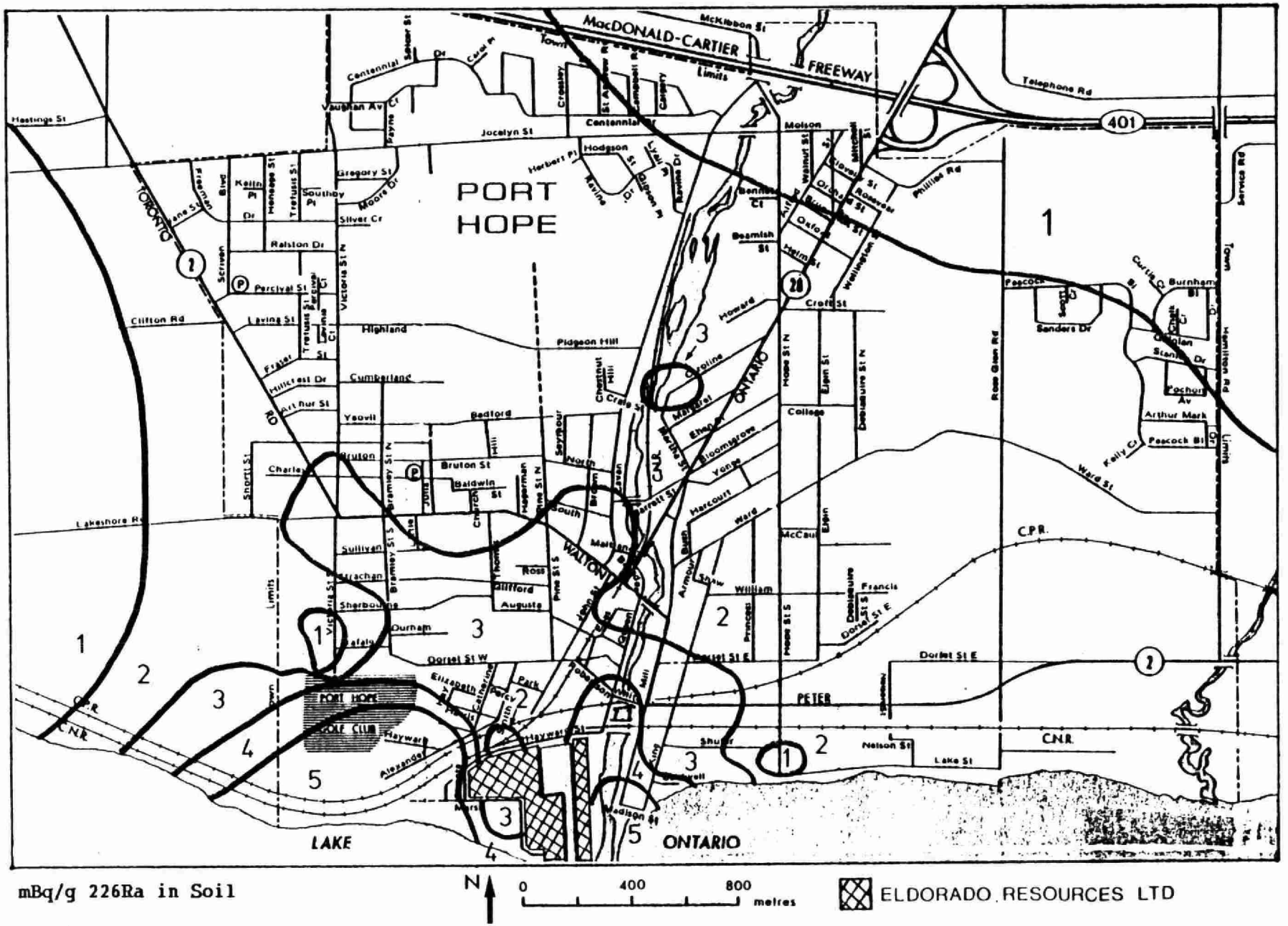


Figure 27: Contours of ^{226}Radium in Soil, as Estimated by SYMAP (1987, 0-5 cm depth).

23 sample sites. The maximum activity was detected at Site 7, about 300 m W of ERL. At 1500 mBq/g, this was about 37 times higher than the reported background level. Soil activities of ^{226}Ra in excess of 500 mBq/g occurred up to 360 m E of ERL. By comparison, the ^{226}Ra activity of U ore tailings at Elliott Lake exceeds 6000 mBq/g.

Figure 28 is a SYMAP illustrating contours of ^{210}Pb activity in soil. The farm field soil was not analyzed for Pb^{210}; therefore, there is no local level with which to compare the town soil survey results. However, the literature suggests that the background soil ^{210}Pb activity ranges from 40 to 100 mBq/g. The ^{210}Pb activity detected in the Port Hope survey ranged from 40 mBq/g to 1000 mBq/g. The area of distinctly elevated activity (greater than 500 mBq/g) occurred directly north and northeast of ERL, south of the railway and west of the river. By comparison, the ^{210} Pb activity of U ore tailings at Elliott Lake averages about 1300 mBq/g.

The same caution should be exercised when interpreting the radionuclide SYMAPs (Figures 26 to 28) as the SYMAPs for the 1986 soil survey data (Figures 6 to 17). The contamination contours on the maps are calculated by the computer program and are therefore only mathematical estimates of the contamination areas. When the 1987 inorganic element SYMAPs were prepared from the intensified survey it was found that the 1986 SYMAPs, which were based on a smaller number of data points, tended to over-estimate the size of the zones of higher concentrations. It is quite possible that the 1987 radionuclide SYMAPs also have over-estimated the areas of greatest activity in a similar manner.

14. Origin of Radionuclide Contamination

In the 1940's and 1950's, manufacturing waste from ERL (formerly Eldorado Nuclear Ltd.) was disposed of in several areas in the town of Port Hope. The AECL has identified these historical waste sites and clean-up has been achieved. However, soil contamination with low level radioactive waste is still a concern to AECL at seven locations: 1) Rollins Ravine, 2) Port Hope Municipal landfill, 3) Brewery Pond Dam, 4) Alexander St. Ravine,

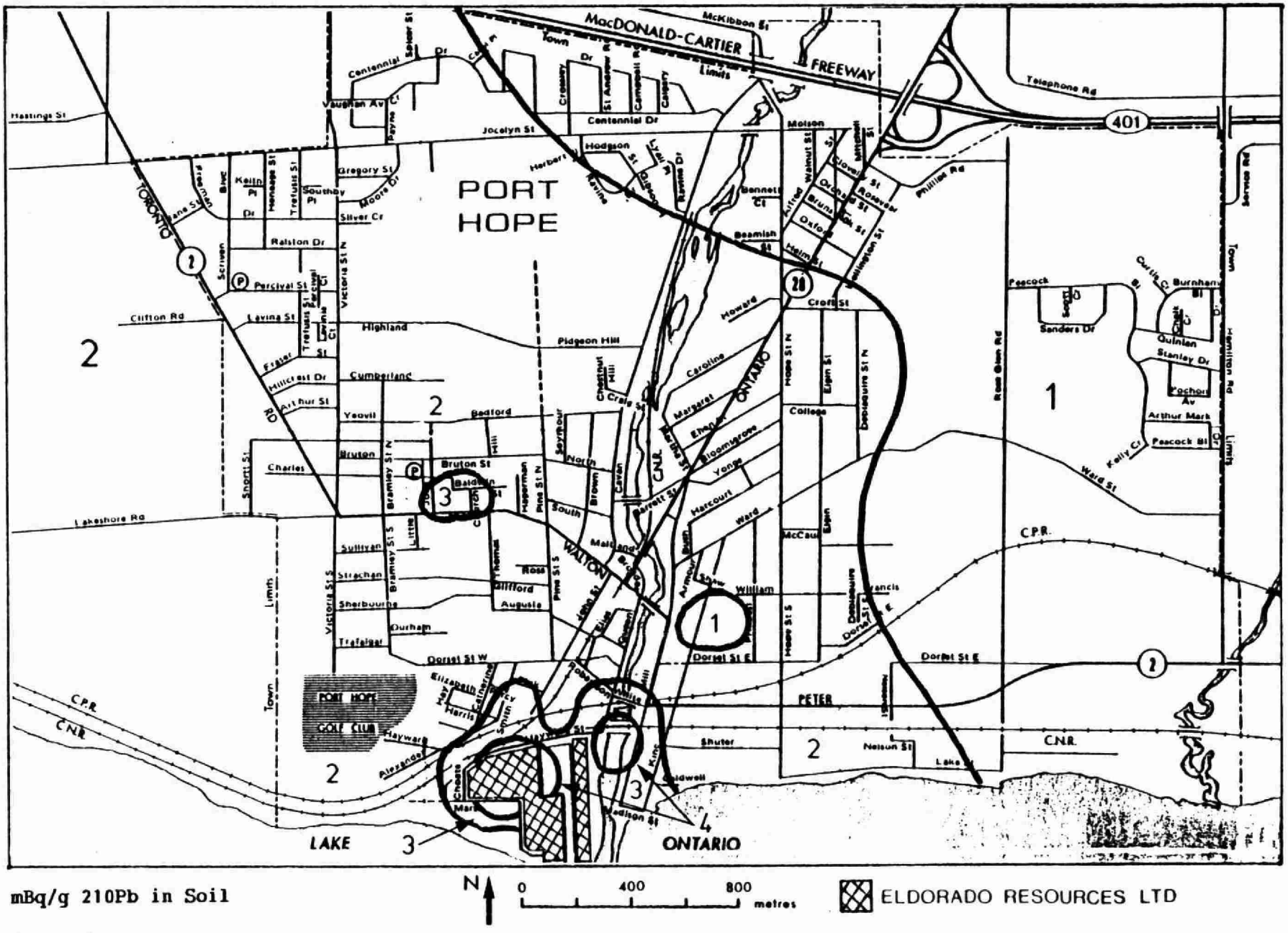


Figure 28: Contours of ^{210}Lead in Soil, as Estimated by SYMAP (1987, 0-5 cm depth).

4) Alexander St. Ravine, 5) Strachan St. Ravine, 6) CN/CP viaducts (Queen and Hayward St. area) and 7) the Port Hope Waterworks. The AECL is presently characterizing the waste at these sites and formulating remedial action plans.

These seven areas of known low level radioactive waste disposal were deliberately avoided during the 1986 and 1987 Phytotoxicology soil surveys, which were designed to examine more widespread contamination patterns.

Unlike U and As, radionuclides are not currently associated with ERL stack or process emissions. Therefore, radionuclides (^{238}U, ^{226}Ra and ^{210}Pb) detected in the Phytotoxicology soil survey may not have originated from atmospheric emission deposition but could be associated with waste disposal operations. The elevated soil radionuclide activity identified by the soil survey occurred in four areas, all of which are in close proximity to ERL. Three of these are in the general vicinity of known historical waste disposal sites (Alexander St. Ravine, the Port Hope Waterworks by Marshal St., and the CN/CP viaducts by Queen and Hayward Sts.). Since the known disposal locations were avoided in this survey, contamination in the vicinity of these three known disposal sites appears to have been more extensive than previously believed. Also, it appears that another former disposal area exists on the east side of the Ganaraska River south of the railway in the Mill St. and Madison St. area. This corresponds to the fourth area of elevated radionuclide activity.

It is also possible that the radionuclide contamination gradient identified in the survey docs not solely reflect the proximity to historical waste sites but rather may also be related to long-term fugitive radionuclide emissions from the ERL manufacturing complex and/or decay of elemental U deposited from chronic stack emissions. The possibility also exists that radionuclides may have been released directly through historic stack emissions. The company has been processing U at its present site in Port Hope for about 35 years and Ra was processed in the early years of the plant operation.

The pattern of contamination is consistent with the concept of fugitive emissions and/or decay of atmospherically deposited U, in that elevated radionuclide activity occurred within 800 m E and W and and about 400 m N of ERL. Also, similarly elevated activity was not detected at the sample sites in the vicinity of the two other more distant historical waste disposal sites. The pattern of radionuclide soil contamination, particularly ^{226}Ra, is very similar to the U contamination contours.

15. Soil Contaminant Inter-relationships

Table 13 is a summary of significant correlation coefficients for the 15 radionuclides and elements included in the 1987 Phytotoxicology soil survey. The data were not normally distributed and varied substantially in absolute concentration; therefore, they were log transformed in order to calculate the individual correlation coefficients. These data corroborate the similarity in the patterns of contamination illustrated in many of the SYMAPs. The most frequently related (11 of 15 possible statistically significant correlations) were ^{238}U, ^{226}Ra, Cu, Ni and Zn. These were followed closely by Pb, U and As, which were each significantly correlated with at least 10 other elements or radionuclides. Only ^{228}Ra and Th^{228} (generally not detected in soil) were not correlated significantly ($p > 0.05$) with any other contaminant; whereas Cr was related only weakly to ^{210}Pb. All the other radionuclides and elements were significantly inter-related with at least seven contaminants.

Dispersion climatology and stack modelling conducted by Environment Canada concluded that the zone of greatest long term deposition of atmospheric emissions from ERL would occur between 300 and 500 m in a north easterly and easterly direction from the source, reflecting the predominant southwesterly wind. However, dispersion is strongly influenced by both Lake Ontario and the local topography, which would tend to channel emissions from ERL in an east and west direction parallel to the shoreline or up the Ganaraska River valley. This is precisely the pattern of soil contamination observed in 1986 and 1987. A similar contamination gradient was documented using moss bags around ERL in 1982 and 1984 for both F and U (McLaughlin, 1986). Soil survey data reveal contamination

Table 13: Summary of Significant Correlation Coefficients Between Radionuclides and Inorganic Elements in Soil Collected in the 1987 Phytotoxicology Survey.

Element/ Radionuclide	^{228}Th	^{226}Ra	^{228}Ra	^{40}K	^{210}Pb	U	As	Cd	Cr	Cu	Ni	Pb	Zn	Sb	Se
^{238}U	ns	***	ns	***	*	***	***	ns	ns	***	*	**	**	***	*
^{228}Th		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
^{226}Ra			ns	***	*	***	***	***	ns	***	***	***	***	***	*
^{228}Ra				ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
^{40}K					ns	***	**	ns	ns	***	**	ns	***	***	ns
^{210}Pb						**	ns	ns	*	ns	ns	ns	ns	ns	ns
U							***	ns	ns	***	*	***	**	***	*
As								**	ns	***	*	***	***	ns	***
Cd									ns	**	*	**	***	ns	**
Cr										ns	ns	ns	ns	ns	ns
Cu											***	***	***	***	**
Ni												***	***	**	**
Pb													***	**	**
Zn														***	*
Sb															ns

* p <0.05
** p <0.01
*** p <0.001
ns - not significant (p >0.05)

originating from chronic, long term deposition; whereas, moss bag data mainly identify current monthly deposition. The fact that both the soil and moss bag data show very similar contamination gradients strongly suggests that the soil contamination resulted from chronic atmospheric deposition as opposed to originating from the haphazard disposal of refinery waste. Fugitive emissions, particularly in the earlier years when emissions were less controlled and general housekeeping less efficient, undoubtedly contributed to the off-site contamination in the general vicinity of the ERL complex.

16. Implications of Soil Contamination

The soil on some residential and municipal properties in the vicinity of ERL contains elevated levels of ^{226}Ra, ^{238}U, Cu, Ni, Pb, Zn, U, As and to a lesser extent Sb, Cd and ^{210}Pb. Health and Welfare Canada has conducted a series of studies on the potential radiological hazard of consuming vegetables grown in soil contaminated with levels of ^{226}Ra, ^{238}U and U similar to those encountered in the vicinity of ERL. These studies concluded that there was neither a radiological nor a chemical hazard in consuming vegetables grown in residential gardens in Port Hope contaminated with soil Ra and U levels similar to those detected in the 1986 and 1987 Phytotoxicology surveys (Tracey et al., 1983).

Although U soil concentrations of 100 to 200 ppm would not appear (based on Federal Government studies) to present a radiological or chemical hazard, this concentration range is potentially phytotoxic. Reductions in the yield of sensitive plant species (mostly cereal crops) have been reported in soil with U concentrations in the range of 30 to 50 ppm. The area of concern would thus encompass residential properties on Mill and King Sts. south of Dorset St. E, the east and west ends of Shuter St., Madison and Caldwell Sts., and Hayward, Alexander and Harris Sts. Commercial and municipal properties on Marsh, Choate, Robertson, the south end of Queen St., and Elorado Place would also be included in this zone. Three municipal parks are included as well. They are: 1) south of

Madison St, east of the marina, 2) the east end of the beach park southwest of Marsh St., and 3) the south end of the park that straddles the Ganaraska River, north of the railway viaducts (see Figure 21).

Similarly, As can be toxic to the growth of sensitive species of plants at soil concentrations as low as 25 ppm. Figure 23, the As SYMAP, indicates that potentially phytotoxic As soil concentrations exist in approximately the same area of potentially phytotoxic soil U contamination.

Soil Pb concentrations in excess of 500 ppm can result in Pb levels in washed root and leafy vegetable crops which exceed the long-term consumption guideline of 0.5 ppm fresh weight suggested by Health and Welfare Canada. Soil Pb levels above 500 ppm (see Figure 22) were detected in only two areas in Port Hope; 1) the general area south of the railway viaduct on the west shore of the Ganaraska River, and 2) a few residential properties adjacent to Madison St. at the base of Mill and King Streets.

Although the 1986 and 1987 soil surveys identified areas where Cu, Zn and Cd concentrations exceeded the Phytotoxicology recommended clean-up guidelines for residential/parkland land use, the exceedances were not widespread and the elevated levels were present at sites where contamination by As and Pb was of greater concern. In contrast, Sb exceeded the provisional clean-up guideline at about one quarter of the sample sites. Relatively little is known regarding the hazards of Sb in soil. Phytotoxicity has not been documented at soil Sb concentrations as high as 100 to 200 ppm.

The question that is yet to be fully addressed is that of the potential health effects of direct exposure to soil containing high U, Pb and Sb concentrations. Direct exposure would only be a concern on residential property, parks and publicly accessible areas. The two municipal parks (by the marina south of Madison St. and by the beach southwest of Marsh St.) have relatively low soil Pb concentrations, in fact among the lowest detected in the Port Hope survey, although the U, As and Sb levels are

high. In contrast, soil Pb concentrations between 500 ppm and 1000 ppm occurred on a few residential properties in the Madison St. area, and levels of over 1000 ppm were detected in soil on the west shore of the Ganaraska River south of the railway viaduct. This is a very popular fishing area, particularly for young people. The remedial action plan to clean up soil Pb pollution in the vicinity of secondary Pb smelters in Toronto included a soil removal program because of the suspected linkage between high soil Pb levels and elevated children's blood Pb. Soil exceeding 500 ppm Pb on residential properties was excavated to a depth of 30 cm and replaced with uncontaminated soil.

The soil U concentrations south of Dorset St. in Port Hope are similar to or several times higher than those encountered in U mine tailings in Elliot Lake (between 20 and 200 ppm). This includes the public area by the west river shore, all of the park by the marina, part of the park by the Marsh St. beach (although not the beach itself or the soil around the children's play set) and many residential properties. In fact, based on the SYMAP contamination contours in Figure 21, about 20 residential properties may have soil U concentrations greater than 50 ppm, and several hundred residences could have soil U concentrations in excess of the tentative ULN value of 5 ppm.

The soil data from this report should be examined by the local Medical Officer of Health, the AECL, and Health and Welfare Canada, so that the health implications of all documented soil contamination are fully explored.

17. Conclusions and Summary

The 1986 and 1987 Phytotoxicology surveys in Port Hope indicate that ERL is an ongoing atmospheric source of U, F and to a lesser extent As. However, the 1986/87 U and F concentrations in tree foliage are quite low, relative to those encountered in the late 1970's and early 1980's. The soil survey revealed that surface soil concentrations of U, Cu, Ni,

Pb, Zn, Fe, As, Co, Cr and Sb exceeded Phytotoxicology guidelines, with the U, As and Sb exceedances being substantial. In addition, the radionuclides ^{226}Ra, ^{210}Pb and ^{238}U were detected in soil at activities which consistently exceeded reported background values. The soil contamination gradients for U, As, Sb, ^{238}U, ^{226}Ra and ^{210}Pb clearly indicate that the ERL complex is the main source. There were three areas where the soil was contaminated with most elements and radionuclides and where the concentrations were consistently the highest: 1) north of ERL, south of the railway viaduct and along the west shore of the Ganaraska River, 2) on the east side of the river between the marina and the railway viaduct, and 3) to the west of ERL between the beach and the Alexander St. ravine. These areas are mostly within 500 m of ERL and correlate well with the zone of greatest long term deposition of atmospheric emissions as estimated by AES dispersion modellers. Historical disposal of refinery residue is known to have occurred in this area, although the specific disposal sites were avoided for the 1986/87 soil surveys.

The vertical (depth) concentration profile (Table 9) was not consistent with current atmospheric deposition as the sole source of soil contamination. If this were the case, soil concentrations of most elements would consistently be highest in the surface soil (0 to 5 cm) and decrease with increasing depth. This is due to their fairly immobile nature which results from the adsorption by clays and organic matter. Although this pattern is evident at many sample sites it is not universal, especially in the higher concentration areas. It is likely that atmospheric emissions were much higher in the early years of operations at ERL, and have been reduced substantially or even abated entirely (except for U, F, and As) in the most recent 10 to 15 years. It is also possible that the historical waste disposal sites are more extensive than previously believed, or that fugitive emissions (that is, contamination spread by ground level winds, surface water runoff and physical transport by pedestrian or vehicular traffic from one area to another) may have occurred from the disposal areas or even directly from the ERL complex. The company has operated on its present

site for more than 40 years and the history of plant emissions, refinery waste disposal, and on-site industrial activity has been long and complex.

Soil concentrations of As, U and at a few sites Pb, and possibly Sb, are high enough to be phytotoxic. Health and Welfare Canada has studied vegetable produce grown in Port Hope gardens contaminated with U and Ra and concluded that consumption of these crops does not present either a chemical or radiological hazard. However, the implications of health effects from exposure to soil contaminated with other elements and radionuclides at the concentrations encountered in some areas of Port Hope has not been fully examined. Therefore, the soil survey data should be reviewed by the appropriate medical authorities to determine if soil remedial action is warranted.

RE3098

Table 14
Clean-up Guidelines for Soils

Parameter[b]	Criteria for Proposed Land Use[a,c]			
	Residential/ Parkland/Agricultural[d]		Commercial/Industrial	
	Medium & Fine Textured Soils	Coarse Textured Soils[e]	Medium & Fine Textured Soils	Coarse Textured Soils[e]
pH (recommended range)	6-8	6-8	6-8	6-8
EC (mS/cm)[h]	2	2	4	4
SAR[i]	5	5	12	12
Arsenic	25	20	50	40
Cadmium	4[a1]	3[a1]	8[a1]	6[a1]
Chromium (VI)	10	8	10	8
Chromium (total)	1000	750	1000	750
Cobalt	50	40	100	80
Copper	200[a2]	150[a2]	300	225
Lead	500[a1]	375[a1]	1000[a1]	750[a1]
Mercury	1[a1]	0.8[a1]	2[a1]	1.5[a1]
Molybdenum	5[a2]	5[a2]	40	40
Nickel	200	150	200	150
Nitrogen (%)	0.5[f]	0.5[f]	0.6[f]	0.6[f]
Oil and Grease (%)	1[g]	1[g]	1[g]	1[g]
Selenium	2[a2]	2[a2]	10	10
Silver	25	20	50	40
Zinc	800	600	800	600

Notes:

a. Clean-up guidelines recommended by the Phytotoxicology Section, Air Resources Branch, Ministry of the Environment. The guidelines are based primarily on phytotoxicity, except for (a^1), based on human health, and (a^2), based on health of grazing animals.

b. All units are in ppm (ug/g), dry weight, unless otherwise stated.

c. For comparison with these guidelines, analyses for metals and metalloids must be conducted using an approved strong, mixed-acid digestion procedure. Contact the Laboratory Services Branch of MOE if in doubt about acceptable methods.

d. Guidelines have been endorsed by the OMAF/MOE/MOH Sludge Utilization Committee.

e. Defined as greater than 70% sand and less than 17% organic matter.

f. If N levels exceed the guidelines, the mineralization potential of the soils should be evaluated. Additions of N-based fertilizer may be counter-productive.

g. Guideline given is for fresh oil; for weathered oil (min. 2 yr. exposed on site), the guideline is 2%.

h. EC = electrical conductivity (saturation extract).

i. SAR = sodium adsorption ratio.

Table 15
Provisional Clean-up Guidelines for Soils

Parameter[b]	Criteria for Proposed Land Use[a,c,d]			
	Residential/Parkland		Commercial/Industrial	
	Medium & Fine Textured Soils	Coarse Textured Soils[e]	Medium & Fine Textured Soils	Coarse Textured Soils[e]
Antimony	25	20	50	40
Barium	1000	750	2000	1500
Beryllium	5	4	10	8
Vanadium	250	200	250	200

Notes:

a. These guidelines are tentative; actual permissible levels of contaminants may vary according to site-specific circumstances. Further information on the application of these guidelines may be obtained from the Phytotoxicology Section of the Air Resources Branch, Ministry of the Environment.

b. All units are in ppm (ug/g), dry weight.

c. For comparison with these guidelines, analyses must be conducted using an approved strong, mixed-acid digestion procedure. Contact the Laboratory Services Branch of MOE if in doubt about acceptable methods.

d. These provisional guidelines apply to soil of minimum pH 6.

e. Defined as greater than 70% sand and less than 17% organic matter.

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